H I L G A R D I A

A Journal of Agricultural Science Published by the California Agricultural Experiment Station

VOL. 29 OCTOBER, 1959 No. 2

THE INTEGRATED CONTROL CONCEPT[1]

VERNON M. STERN, RAY F. SMITH, ROBERT van den BOSCH, and KENNETH S. HAGEN[2]

ALL ORGANISMS are subjected to the physical and biotic pressures of the environments in which they live, and these factors, together with the genetic make-up of the species, determine their abundance and existence in any given area. Without natural control, a species which reproduces more than the parent stock could increase to infinite numbers. Man is subjected to environmental pressures just as other forms of life are, and he competes with other organisms for food and space.

Utilizing the traits that sharply differentiate him from other species, man has developed a technology permitting him to modify environments to meet his needs. Over the past several centuries, the competition has been almost completely in favor of man, as is attested by decimation of vast vertebrate populations, as well as populations of other forms of life (Thomas, 1956). But while eliminating many species, as he changed the environment of various regions to fit his needs for food and space, a number of species, particularly among the Arthropoda, became his direct competitors. Thus, when he subsisted as a huntsman or foraged for food from uncultivated sources, early man was largely content to share his subsistence and habitat with the lower organisms. Today, by contrast, as his population continues to increase (Hertzler, 1956) and his civilization to advance, he numbers his arthropod enemies in the thousands of species (Sabrosky, 1952).

The increase to pest status of a particular species may be the result of a single factor or a combination of factors. In the last century, the most significant factors have been the following.

First, by changing or manipulating the environment, man has created conditions that permit certain species to increase their population densities

[1] Received for publication October 24, 1958. This investigation (including those parts reported in the other two papers of this issue) was supported in part by research grants nos. E 885 and E 2192 from the National Institute of Allergy and Infectious Diseases of the National Institutes of Health, Public Health Service.

[2] Mr. Stern is Assistant Entomologist in Entomology, Citrus Experiment Station, Riverside; Mr. Smith is Associate Professor of Entomology and Associate Entomologist in the Experiment Station, Berkeley; Mr. van den Bosch is Associate Entomologist in Biological Control, Citrus Experiment Station, Riverside; and Mr. Hagen is Associate Entomologist in Biological Control in the Experiment Station, Berkeley.

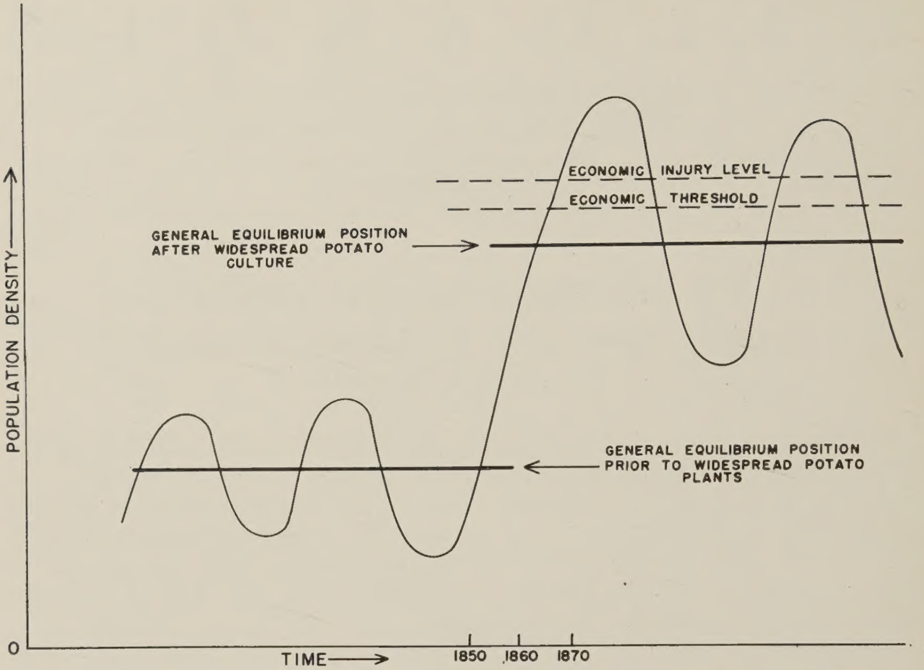


Fig. 1. Schematic graph of the change in general equilibrium position of the Colorado potato beetle, *Leptinotarsa decemlineata* following the development of widespread potato culture in the United States. For a discussion of the significance of economic-injury levels and economic thresholds in relation to the general equilibrium position, see p. 89.

(Ullyett, 1951). The rise of the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), to pest status occurred in this manner (see fig. 1). When the potato, as well as other solanaceous plants, was brought under widespread cultivation in the United States, a change favorable to the beetle occurred in the environment, which enabled it to become very quickly an important pest (Trouvelot, 1936). Similarly, when alfalfa, *Medicago sativa* L., was introduced into California about 1850, the alfalfa butterfly, *Colias philodice eurytheme* Boisduval, which had previously occurred in low numbers on native legumes, found a widespread and favorable new host plant in its environment, and it subsequently became an economic pest (Smith and Allen, 1954).

A second way in which arthropods have risen to pest status has been through their transportation across geographical barriers while leaving their specific predators, parasites, and diseases behind (Smith, 1959). The increase in importance through such transportation is illustrated by the cottony cushion scale, *Icerya purchasi* Maskell (see fig. 2). This scale insect was introduced into California from Australia on acacia in 1868. Within the following two decades, it increased in abundance to the point where it threatened economic disaster to the entire citrus industry in California. Fortunately, the timely importation and establishment of two of its natural ene-

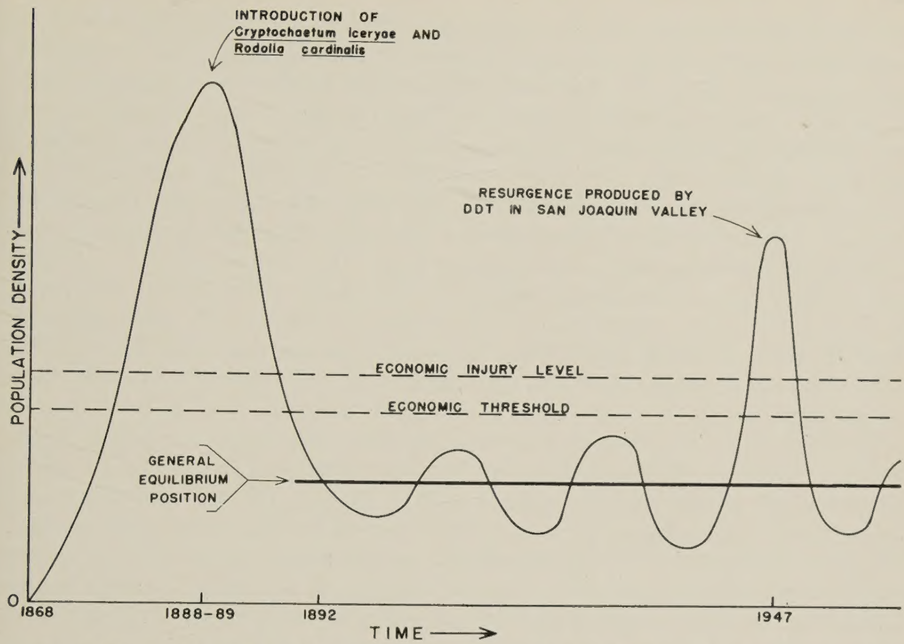


Fig. 2. Schematic graph of the fluctuations in population density of the cottony cushion scale, *Icerya purchasi,* on citrus from the time of its introduction into California in 1868. Following the successful introduction of two of its natural enemies in 1888 this scale was reduced to noneconomic status except for a local resurgence produced by DDT treatments.

mies, *Rodolia cardinalis* (Mulsant) and *Cryptochaetum iceryae* (Williston), resulted in the complete suppression of *I. purchasi* as a citrus pest (Doutt, 1958).

The cottony cushion scale again achieved the status of a major pest when the widespread use of DDT on citrus in the San Joaquin Valley eliminated the vedalia (Ewart and DeBach, 1947).

A third cause for the increasing number of pest arthropods has been the establishment of progressively lower economic thresholds (see p. 89 for definition and discussion). This can be illustrated by lygus bugs (*Lygus* spp.) on lima beans. Not too many years ago the blotches caused by lygus bugs feeding on an occasional lima bean were of little concern, and lygus bugs were considered a minor pest on this crop. However, with the emphasis on product appearance in the frozen-food industry, a demand was created for a near-perfect bean. For this reason, economic-injury thresholds were established and lygus bugs are now considered serious pests of lima beans.

In the face of this increased number of arthropod pests man has made remarkable advances in their control, and economic entomology has become a complex technical field. Of major importance have been new developments in pesticide chemistry and application.

The discovery of the insecticidal properties of DDT, and its spectacularly successful application to arthropod-borne disease and agricultural pest problems, spurred research in chlorinated hydrocarbon chemistry and stimu-

lated the development of other organic pesticides. On a national scale, the experiment stations, state and governmental agencies, and commercial companies, all searching for new or better answers to old insect-pest problems, eagerly accepted the new chemicals. Within a short period many became an integral part of public health and agricultural pest-control programs. Without question, the rapid and widespread adoption of organic insecticides brought incalculable benefits to mankind, but it has now become apparent that this was not an unmixed blessing. Through the widespread and sometimes indiscriminate use of pesticides, the components and intricate relations of crop environments have been drastically altered, and as a result a number of serious problems have arisen (Wigglesworth, 1945; Michelbacher, 1954; Pickett, 1949; Pickett and Patterson, 1953; Solomon, 1953; and others). Among these new problems and old ones which have been aggravated are:

1. Arthropod resistance to insecticides. This phenomenon relating to the genetic plasticity of the arthropods has been reviewed by Metcalf (1955), Hoskins and Gordon (1956), Crow (1957), Brown (1959), and others. In many cases, resistance is already drastic enough to have eliminated certain insecticides from important pest-control programs. There are today in excess of 70 demonstrated cases of arthropod resistance. Actually, a much larger number of pest species exist which are developing resistance or have already done so, but there has not been time to evaluate these cases.

2. Secondary outbreaks of arthropods other than those against which control was originally directed (Massee, 1954; DeBach and Bartlett, 1951; Ripper, 1956; and others). These outbreaks usually result from the interference of the insecticide with biological control (Lord, 1947; Bartlett and Ortega, 1952; Michelbacher, 1954; Michelbacher and Hitchcock, 1958; and others). This may also occur through the effect of the insecticide on the plant, which, in turn, affects the development of the secondary pest (Fleschner and Scriven, 1957). An example is the increase in mites on plants growing in soil receiving certain chemical treatments (Klostemeyer and Rasmussen, 1953).

3. The rapid resurgence of treated species necessitating repetitious insecticide applications (Holloway and Young, 1943; Bovey, 1955; Schneider, 1955; Stern and van den Bosch, 1959; and others). These flarebacks occur from individuals surviving treatment or from individuals migrating into the treated area, where they can reproduce unhindered because their natural enemies have been eliminated.

4. The toxic insecticide residues on food and forage crops (Brown, 1951; Linsley, 1956). This problem may result from two sources. First, untimely applications or accidental increases in dosage may result in residues above the tolerance limits. Second, the first three problems mentioned above are interrelated and by aggravating one another may lead to excessive treatment and a residue problem. For example, where the level of resistance is increasing, it requires either more frequent applications or higher insecticide dosages to control the pest, or both. This increased insecticide program may in turn have a drastic effect on the ecosystem, which frequently results in outbreaks of secondary pests or rapid resurgence of the resistant pest

for which control was originally intended. Often, under such conditions, where insects threaten the crop or marketability of a crop close to harvest, the grower is faced with the problem of suffering a severe monetary loss or of making an insecticide application closer to harvest than is ordinarily permissible. In many instances, the end result is a residue far above the accepted tolerance limit at harvest time.

5. Hazards to insecticide handlers and to persons, livestock, and wildlife subjected to contamination by drift (Hayes, 1954; Petty, 1957; Upholt, 1955).

6. Legal complications from suits and other actions pertaining to the above problem.

Unquestionably, some of these problems have arisen from our limited knowledge of biological science; others are the result of a narrow approach to insect control. Few studies have included basic investigations on the effects the chemicals might have on other components of the ecosystems to which the pests belong. The entomologist may recognize the desirability of a thorough investigation of these aspects, but because of the need for immediate answers to pressing problems and because of other pressures, he does not have the necessary time. In other instances because fundamental knowledge is lacking, the investigator may be unaware of the intricate nature of the biotic complex with which he is dealing, and of the destructive potential that many chemicals in use today have on the environment of the pests. Finally, and most unfortunately, there are workers who are highly skeptical that biotic factors are of any consequence in the control of pest population densities and thus choose to ignore any approach to pest control other than the use of chemicals.

Whatever the reasons for our increased pest problems, it is becoming more and more evident that an integrated approach, utilizing both biological and chemical control, must be developed in many of our pest problems if we are to rectify the mistakes of the past and avoid similar ones in the future (DeBach, 1951, 1958*a*; Pickett, Putman, and Roux, 1958; Ripper, 1944; Huffaker and Kennett, 1956; Wille, 1951; Michelbacher and Middlekauff, 1950; and others).

TERMINOLOGY

To clarify the discussion in other parts of this paper some definitions and explanations of terms are here given:

Biological control. *The action of parasites, predators, or pathogens on a host or prey population which produces a lower general equilibrium position than would prevail in the absence of these agents.* Biological control is a part of natural control (*q.v.*) and in many cases it may be the key mechanism governing the population levels within the framework set by the environment. If the host or prey population is a pest species, biological control may or may not result in economic control. Biological control may apply to any species whether it is a pest or not, and regardless of whether or not man deliberately introduces, manipulates, or modifies the biological-control agents.

Biotic insecticide. *A biotic mortality agent applied to suppress a local insect pest population temporarily.* The effects of the agent usually do not persist and they are similar to those resulting from the use of a chemical insecticide in that they do not produce a permanent change in the general equilibrium position. A polyhedrosis virus applied as a spray to control the alfalfa caterpillar is a typical example of a biotic insecticide. Preparations of microörganisms used in this manner are sometimes referred to as *microbial insecticides.* Predators, such as lady beetles, or parasites, when they are released in large numbers, can also act, in some instances, as biotic insecticides.

Biotic reduction. *Deaths or other losses to the population* (e.g., *dispersal, reduced fecundity*) *caused or induced by biotic elements of the environment in a given period of time.*

Economic control. *The reduction or maintenance of a pest density below the economic-injury level* (q.v.).

Economic-injury level. *The lowest population density that will cause economic damage.* Economic damage is the amount of injury which will justify the cost of artificial control measures; consequently, the economic-injury level may vary from area to area, season to season, or with man's changing scale of economic values.

Economic threshold. *The density at which control measures should be determined to prevent an increasing pest population from reaching the economic-injury level.* The economic threshold is lower than the economic-injury level to permit sufficient time for the initiation of control measures and for these measures to take effect before the population reaches the economic-injury level.

Ecosystem. *The interacting system comprised of all the living organisms of an area and their nonliving environment.* The size of area must be extensive enough to permit the paths and rates of exchange of matter and energy which are characteristic of any ecosystem.

General equilibrium position. *The average density of a population over a period of time* (*usually lengthy*) *in the absence of permanent environmental change.* The size of the area involved and the length of the period of time will vary with the species under consideration. Temporary artificial modifications of the environment may produce a temporary alteration of the general equilibrium position (*i.e.,* a temporary equilibrium).

Governing mechanism. *The actions of environmental factors, collectively or singly, which so intensify as the population density increases and relax as this density falls that population increase beyond a characteristic high level is prevented and decrease to extinction is made unlikely.* The governing mechanisms operate within the framework or potential set by the other environmental elements.

Integrated control. *Applied pest control which combines and integrates biological and chemical control.* Chemical control is used as necessary and in a manner which is least disruptive to biological control. Integrated control may make use of naturally occurring biological control as well as biological control effected by manipulated or introduced biotic agents.

Microbial control. *Biological control that is effected by microörganisms (including viruses).*

Natural control. *The maintenance of a more or less fluctuating population density within certain definable upper and lower limits over a period of time by the combined actions of abiotic and biotic elements of the environment.* Natural control involves all aspects of the environment, not just those immediate or direct factors producing premature mortality, retarded development, or reduced fecundity; but remote or indirect factors as well. For most situations, governing mechanisms (*q.v.*) are present and determine the population levels within the framework or potential set by the other environmental elements. In the case of a pest population, natural control may or may not be sufficient to provide economic control.

Natural reduction. *Deaths or other losses to the population caused by naturally existing abiotic and biotic elements of the environment in a given period of time.*

Population. *A group of individuals of the same species that occupies a given area.* A population must have at least a minimum size and occupy an area containing all its ecological requisites to display fully such characteristics as growth, dispersion, fluctuation, turnover, dispersal, genetic variability, and continuity in time. The minimum population and the requisites in occupied area will vary from species to species.

Population dispersion. *The pattern of spacing shown by members of a population within its occupied habitat and the total area over which the given population may be spread.*

Selective insecticide. *An insecticide which while killing the pest individuals spares much or most of the other fauna, including beneficial species, either through differential toxic action or through the manner in which the insecticide is utilized (formulation, dosage, timing, etc.).*

Supervised insect control. *Control of insects and related organisms supervised by qualified entomologists and based on conclusions reached from periodically measured population densities of pests and beneficial species.* Ideally, supervised control is based on a sound knowledge of the ecology of the organisms involved and projected future population trends of pests and natural enemies.

Temporary equilibrium position. *The average density of a population over a large area temporarily modified by a procedure such as continued use of insecticides.* The modified average density of the population will revert to the previous or normal density level when the modifying agent is removed or expended (*cf.* "general equilibrium position").

THE NATURE AND WORKING PRINCIPLES OF BIOLOGICAL AND CHEMICAL CONTROL

Biological Control. Biological controls are part of natural control which governs the population density of pest species. On the other hand, with certain exceptions, chemical controls involve only immediate and temporary decimation of localized populations and do not contribute to permanent

density regulation. This distinction is not always clearly made, and biological control is often thought of as being similar in its action to chemical control. Perhaps one reason for the misunderstanding is that in spectacular instances a biotic agent may act in the manner of a chemical in eliminating a local pest population. For example, this may occur when weather conditions are favorable and disease pathogens eliminate a localized pest population. Parasites and predators may sometimes act in a similar manner. However, the important prevailing characteristic of biological control is one of permanent population-density regulation. Usually these governing mechanisms occur over such a large area and are so subtle or intricate in their action that they are not easily observed and recorded; thus they tend to be overlooked.

A principal phase of applied biological control is the importation and establishment of natural enemies of pests that accidentally gain entry into new geographical regions. These new pests frequently escape the natural enemies that help to regulate their densities in the areas to which they are indigenous (Elton, 1958). Under satisfactory conditions in the new environment, the pest may flourish and reach damaging abundance. As a counter measure, the natural enemies are obtained from the native home of the pest and transplanted into the new environment to increase the biotic resistance of the environment to the pest.

Biological control is thus utilized to permanently increase environmental resistance to an introduced pest. The hope is that the introduced enemies will lower the general equilibrium position of the pest sufficiently to maintain it permanently below the economic threshold. Most often the introduction of a biotic agent is not so spectacular, and it is an exception when the general equilibrium position of the introduced pest is lowered sufficiently to prevent its occasionally or even commonly reaching economic abundance at certain times or places (Clausen, 1956; Simmonds, 1956). This, of course, is precisely the status of a native pest which, though attacked by a complex of parasites and predators, still has a general equilibrium position high enough to permit it occasionally to cause damage of greater or lesser severity. Thus, in any geographic area the governing mechanisms in the environment are constantly at work to counteract the inherent natality of plant and animal pest species. In terms of crop protection, these regulating factors actually keep thousands of potentially harmful arthropod species permanently below economic thresholds. Moreover, these environmental pressures tend to localize the outbreaks of those forms which on occasion are capable of rising above economic thresholds. A biological control agent is self-perpetuating and capable of response to fluctuations in the population density of the pest it attacks. Biological controls, whether imported or native, are permanent characteristics of a given environment.

Chemical Control. Chemical control of an arthropod pest is employed to reduce populations of pest species which rise to dangerous levels when the environmental pressures are inadequate. When chemicals are used, the damage from the pest species must be sufficiently great to cover not only the cost of the insecticidal treatment but also the possible deleterious effects, such as the harmful influence of the chemical on the ecosystem. On some occasions, the pest outbreak may cover a wide area; in other instances, dam-

aging numbers occur in very restricted locations. These outbreaks occur during the season favorable to the pest, with the relaxed environmental pressures occurring some time before the outbreak. Chemical control is only needed at those times and places where natural control is inadequate. Chemical control should act as a complement to the biological control.

An insecticide must always be manipulated by man, who adds it to a restricted segment of the pest's environment to decimate a localized pest population. Because chemical insecticides are nonreproductive, have no searching capacity, and are nonpersistent, they constitute short-term, retricted pressures. They cannot permanently change the general equilibrium position of the pest population nor can they restrain an increase in abundance of the pest without repeated applications. Therefore, they must be added to the environment at varying intervals of time.

In certain pest-control programs, the insecticide is applied over extensive geographical areas. In some areas, after application, the pest population density may be far below the economic threshold and below its general equilibrium position; but since the insecticide is not a permanent part of the environment, the pest may return to a high level when the effects of the insecticide are gone.

The effectiveness of a chemical insecticide or a biotic insecticide is measured in per cent of kill or in per cent of clean fruits, uninjured cotton bolls, and so forth, in the area of application. Such applications have little influence on the pest in adjoining areas except as localized population depressants. In general, this contrasts sharply with the role of the permanent biotic mortality agent, whose effectiveness is best measured by its influence on the general equilibrium position of the pest species over an entire geographical region or a long period of time.

ECONOMIC THRESHOLDS AND THE GENERAL EQUILIBRIUM POSITION

Chemical control should be used only when the economic threshold is reached and when the natural mortality factors present in the environment are not capable of preventing the pest population from reaching the economic-injury level. The economic-injury level is a slightly greater density than the economic threshold. This difference in densities provides a margin of safety for the time that elapses between the detection of the threatening infestation and the actual application of an insecticide. The economic threshold and the economic-injury level of a pest species can vary depending upon the crop, season, area, and desire of man; the general equilibrium position, on the other hand, barring "permanent" changes in the environment, is a fixed population level (Griffiths, 1951; Strickland, 1954).

A species population is plastic and is undergoing constant change within the limits imposed upon it by its genetic constitution and the characteristics of its environment. Typical fluctuations in population and dispersion are shown in figure 3. The population dispersions shown at the three points in time A, B, and C are not static but rather are instantaneous phases of a continuously changing dispersion.

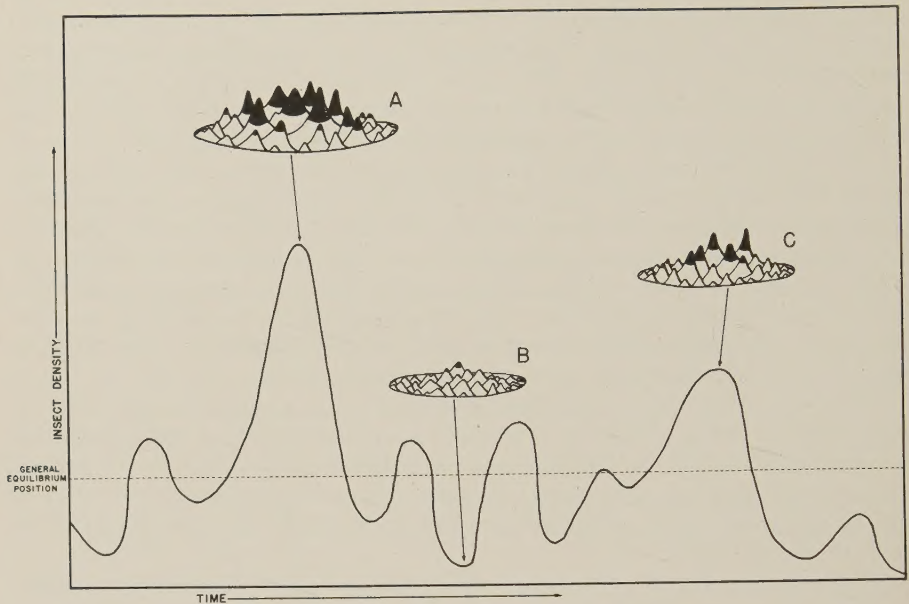


Fig. 3. Schematic graph of the population trend and population dispersion of a pest species over a long period of time. The solid line depicts the fluctuations in the population density with time. The broken line depicts the general equilibrium position. The population dispersion is indicated at the specific times *A*, *B*, and *C*. The basal area of these models reflects the distributional range, the height indicates population density. Population densities above the economic threshold are black.

Thus at point A, when the population is of greatest numerical abundance, it also has its widest distributional range (as depicted by the maximum diameter of the base of the model), and is of maximum economic status (as depicted by the number and magnitude of the blackened pinnacles representing penetrations of the economic threshold). At point B, on the other hand, when the species population is at its lowest numerical abundance, it is also most restricted in geographical range and is of only minor economic status. Point C represents an intermediate condition between points A and B.

In order to determine the relative economic importance of pest species, both the economic threshold and general equilibrium position of the pests must be considered. It is the general equilibrium position and its relation to the economic threshold, in conjunction with the frequency and amplitude of fluctuations about the general equilibrium position, that determine the severity of a particular pest problem.

In the absence of permanent modifications in the composition of the environment, the density of a species tends to fluctuate about the general equilibrium position as changes occur in the biotic and physical components of the environment. As the population density increases, the density-governing factors respond with greater and greater intensity to check the increase; as the population density decreases, these factors relax in their effects. The general equilibrium position is thus determined by the interaction of the

species population, these density-governing factors, and the other natural factors of the environment. A permanent alteration of any factor of the environment—either physical or biotic—or the introduction of new factors may alter the general equilibrium position.

The economic threshold of a pest species can be at any level above or below the general equilibrium position or it can be at the same level. Some phytophagous species may utilize our crops as a food source but even at their highest attainable density are of little or no significance to man (see fig. 4, *A*). Such species can be found associated with nearly every crop of commercial concern.

Another group of arthropods rarely exceeds the economic thresholds and these consequently are occasional pests. Only at their highest population density will chemical control be necessary (see fig. 4, *B*).

When the general equilibrium position is close to the economic threshold, the population density will reach the threshold frequently (see fig. 4, *C*). In some cases, the general equilibrium position and the economic threshold are at essentially the same level. Thus, each time the population fluctuates up to the level of the general equilibrium position insecticidal treatment is necessary. In such species the frequency of chemical treatments is determined by the fluctuation rate about the general equilibrium position, which in some cases necessitates almost continuous treatment.

Finally, there are pest species in which the economic threshold lies below the general equilibrium position; these constitute the most severe pest problems in entomology (see fig. 4, *D*). The economic threshold may be lower than the level of the lowest population depression caused by the physical and biotic factors of the environment, *e.g.*, many insect vectors of viruses. In such cases, particularly where human health is concerned, there is a widespread and almost constant need for chemical control. This produces conditions favorable for development of insecticide resistance and other problems associated with heavy treatments.

One solution to pest problems and particularly those in this last category is to change the environment permanently so that the general equilibrium position will be lowered. For example, this might be accomplished through the introduction of a new biological control agent or through the permanent modification of a large portion of a required habitat. This has been done in certain areas with malaria-vector mosquitoes and similar pests by the draining of swamps and the destruction of other favorable habitats. Such methods may completely eliminate the species from some areas.

Environmental changes unfavorable to the pest may also be made through the use of plants and animals resistant to the pest species. This control method may involve three different aspects—tolerance, preference, and antibiosis (Painter, 1951). If tolerance alone is involved, the general equilibrium position may not be changed but the economic threshold is raised. Where preference or antibiosis is involved, the ability of the pest to reproduce upon the host is reduced, so that the general equilibrium position is lowered.

The lack of a sound measure of economic thresholds, in many cases, has been a major stumbling block to the development of integrated pest-control programs. Our changing economy, variations in natural governing mecha-

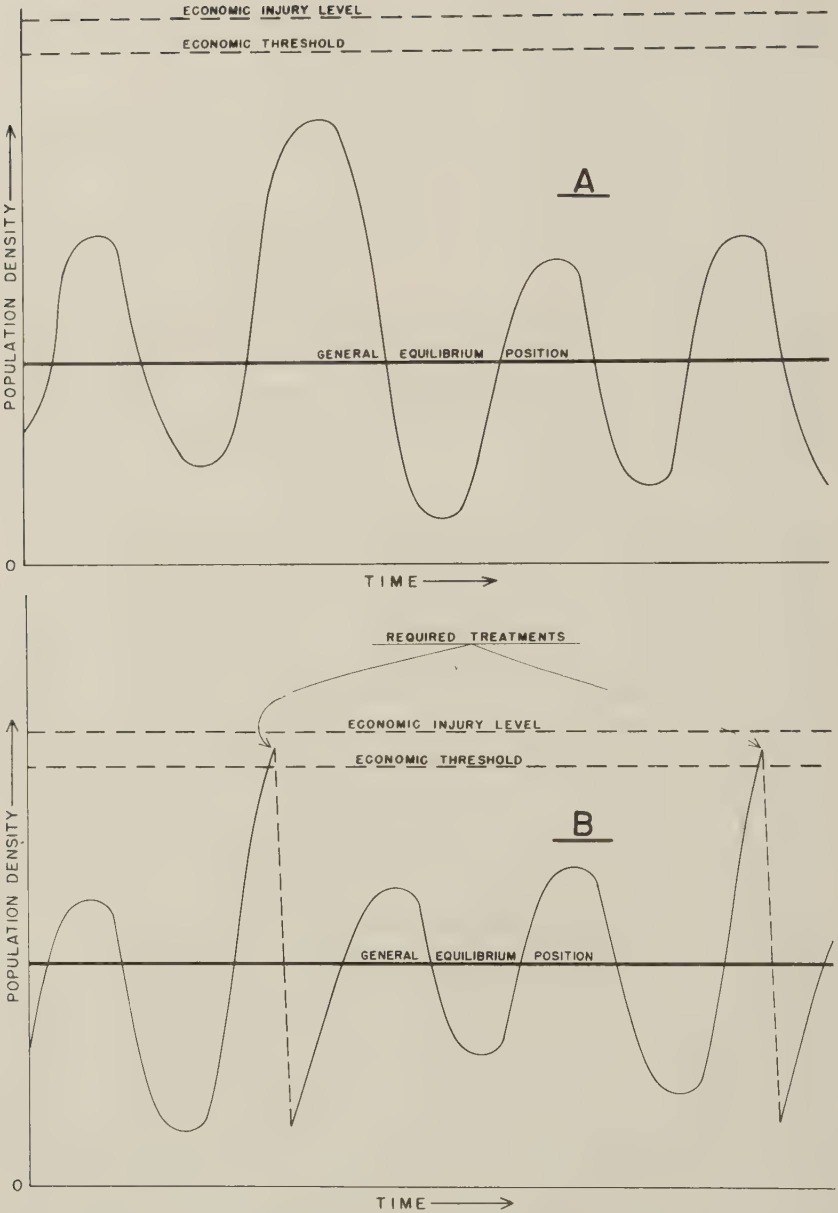
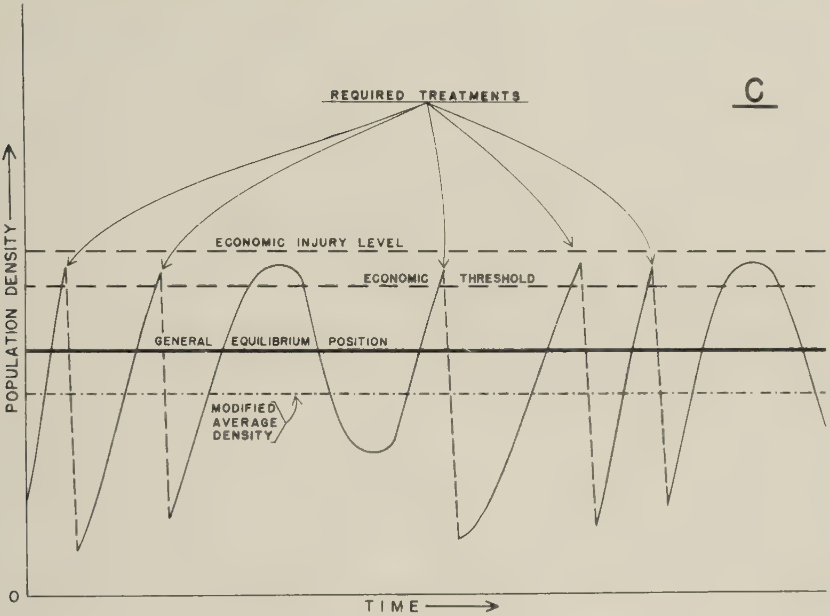
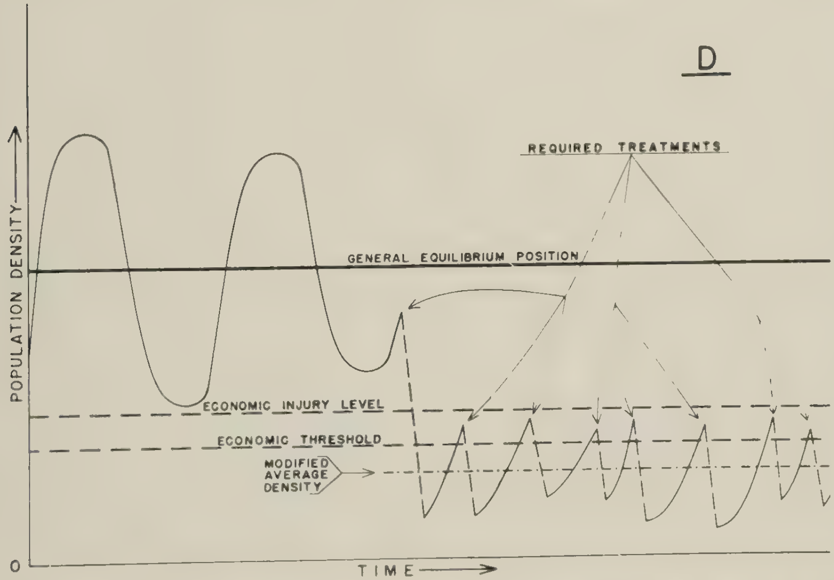


Fig. 4. Schematic graphs of the fluctuations of theoretical arthropod populations in relation to their general equilibrium position, economic thresholds, and economic-injury levels. *A*, Noneconomic population whose general equilibrium position and highest fluctuations are below the economic threshold, *e.g.*, *Aphis medicaginis* Koch on alfalfa in California. *B*, Occasional pest whose general equilibrium position is below the economic threshold but whose highest population fluctuations exceed the economic threshold, *e.g.*,





Grapholitha molesta Busck on peaches in California. *C*, Perennial pest whose general equilibrium position is below the economic threshold but whose population fluctuations frequently exceed the economic threshold, *e.g.*, *Lygus* spp. on alfalfa seed in the western United States. *D*, Severe pest whose general equilibrium position is above the economic threshold and for which frequent and often widespread use of insecticides is required to prevent economic damage, *e.g.*, *Musca domestica* in Grade A milking sheds.

nisms from one geographical area to another, differences in consumer demands, and the complexity of measuring the total effect of insects on yield and quality often make the assessment of economic damage extremely difficult. Yet the economic threshold and the economic-injury level must be determined reasonably and realistically before integrated pest control can develop to its fullest. Success in any well-balanced pest-control program is dependent on the aim of holding insect populations below experimentally established economic levels rather than attempting to eliminate all the insects.

THE INTEGRATION OF BIOLOGICAL AND CHEMICAL CONTROL

Biological control and chemical control are not necessarily alternative methods; in many cases they may be complementary, and, with adequate understanding, can be made to augment one another. One reason for the apparent incompatibility of biological and chemical control is our failure to recognize that the control of arthropod populations is a complex ecological problem. This leads to the error of imposing insecticides on the ecosystem, rather than fitting them into it. It is short-sighted to develop a chemical control program for the elimination of one insect pest and ignore the impact of that program on the other arthropods, both beneficial and harmful, in the ecosystem. On the other hand, this approach is no worse than the other extreme which would eliminate chemicals to preserve the biological control even in the face of serious economic damage. For we must recognize that modern agriculture could not exist without the use of insecticides. The evidence that biological and chemical control can be integrated is mounting. It has come from many sources involving many kinds of pests in various situations: see Ullyett (1947), Pickett and Patterson (1953), Ripper (1956), Huffaker and Kennett (1956), DeBach (1958*a*), Stern and van den Bosch (1959), and many others.

In approaching an integrated control program, we must realize that man has developed huge monocultures, he has eliminated forests and grasslands, selected special strains of plants and animals, moved them about, and in other ways altered the natural control that had developed over thousands upon thousands of years. We could not return to those original conditions if it were desirable. We may, however, utilize some of the mechanisms that existed before man's modifications, to establish new balances in our favor.

Recognition of the Ecosystem. To establish new, favorable balances, it is first necessary to recognize the "oneness" of any environment, natural or man-made. The populations of plants and animals (including man) and the nonliving environment together make up an integrated unit, the ecosystem. If an attempt is made to reduce the population level of one kind of animal (for example, a pest insect) by chemical treatment, modification of cultural practices, or by other means, other parts of the ecosystem will be affected as well. For this reason, the production of a given food or fiber must be considered in its entirety. This includes simultaneous consideration of insects, diseases, plant nutrition, plant physiology, and plant resistance, as well as the economics of the crops (Forbes, 1880; Ullyett, 1947; Pickett, 1949; DeBach, 1951; Solomon, 1953; Pickett and Patterson, 1953;

Glen, 1954; Michelbacher, 1954; Huffaker and Kennett, 1956; Simmonds, 1956; Balch, 1958; Decker, 1958; and others).

In most agricultural ecosystems, some potentially harmful organisms are continually held at subeconomic levels by natural controlling forces. In others, the pests are held below economic levels only part of the time. A pest species may be under satisfactory biological control over a large area or a long period of time, but not in all individual fields or during all periods. In a single field or orchard, or during a portion of a year, the pest population may rise to economic levels, while elsewhere or at other times the pest may be subeconomic. It is in such situations that integrated control programs are especially important. These intermittently destructive populations must be reduced in a manner that permits the biological control which prevailed before or prevails elsewhere to take over again. If a chemical treatment destroys the biotic agents without eradicating the pest, then repeated treatments may become necessary.

Population Sampling and Prediction. The sampling methods utilized by most research investigators for experimental plots are usually too time-consuming and tedious to be of practical value in establishing pest population levels in commercial crops. Special index methods are needed that are rapid and simple to use. Ideally, these should be of such nature that they can be easily utilized by the person examining the crop. But in many cases the grower is not able to evaluate all situations because of the difficulties and complexities involved in determining the status of some pest populations at the times of the year when they must be controlled. Then qualified entomologists will be required to evaluate the populations (Ripper, 1958).

One answer to this problem has been the development of supervised control in California, Arkansas, Arizona, and elsewhere. In a supervised control program the farmer, or a group of farmers, contracts with a professional entomologist who determines the status of the insect populations. On the basis of his population counts, other conditions peculiar to each situation, and his knowledge of the ecology of the pests and their biological controls, the entomologist makes predictions as to the course of the population trends and advises as to when controls should be applied and what kind. For instance, in the case of the alfalfa caterpillar, *Colias philodice eurytheme*, when economic thresholds are reached, the recommended procedure may involve immediate cutting of the hay crop without treatment, application of the polyhedrosis virus (Steinhaus and Thompson, 1949; Thompson and Steinhaus, 1950), or treatment with an insecticide. The course to be taken depends on the characteristics of the particular infestation (Smith and Allen, 1954).

Wherever possible, knowledge must be developed so that we can predict the times when occasional pests will be present in outbreak numbers. This will eliminate unnecessary and environment-disturbing "insurance" treatments. When this is not possible, the treatments can be timed according to the actual pest population levels, as is now done with many field-crop pests.

With those crops that do not yet have fixed chemical control schedules, every effort should be made to plan programs dependent upon pest population levels and to avoid dependence upon insurance and prophylactic treat-

ments. If this is not done there is real danger that on these crops, too, pest-control problems will become increasingly complex.

Augmentation of Natural Enemies. In some situations, the development of integrated control requires the augmentation of the natural-enemy complex (DeBach, 1958*a*). The introduction of additional natural enemies is usually the simplest and best solution. This may not be possible or effective with some pest species, and methods of overcoming the inefficiency of the natural-enemy complex must be sought. This can be done by periodic colonization of parasite or predators (Doutt and Hagen, 1950; DeBach, Landi, and White, 1955), artificial inoculation of the host at times of low density (Smith and DeBach, 1953; Huffaker and Kennett, 1956), modification of the environment, or selective breeding of parasites and predators.

The modification of the environment may involve changes in irrigation, introduction of a covercrop, or development of greater plant heterogeneity. Refuges for beneficial forms can be produced by strip treatments with chemicals (DeBach, 1958*a*) or by the development of uncultivated and untreated areas (Grison and Biliotti, 1953). Modification of the environment may also involve the control of ants or other organisms which curtail parasite and predator activity (Flanders, 1945; DeBach, Fleschner, and Dietrick, 1951). The selective breeding of parasites and predators may be directed toward increased or modified tolerance ranges to physical conditions (DeBach, 1958*b*) or insecticides (Robertson, 1957).

Where prophylactic treatments are proved to be necessary for a perennial pest, selective materials must be developed and utilized to foster biological control both of other pests and of the pest of direct concern at other times.

Selective Insecticides. Chemical control programs are limited by the nature of the available materials. In the past, nonselective insecticides applied for one insect in a pest complex often have eliminated the biotic factors holding other pests in check. More recently, we have had available a greater variety of materials, some of them selective in their action (Ripper, 1956).

The selective use of insecticides may be accomplished in at least four ways. First, the insecticide itself may be selective in its toxicological action. Narrow-range toxicants may be utilized to reduce a pest of concern and at the same time spare the beneficial forms (Ripper, 1944; Ripper, Greenslade, and Hartley, 1951). A particular material may be selective in one situation and not in another; or it may be selective at low dosages but not at high dosages. Furthermore, the manner of application (Ripper, 1956) and especially the type of carrier and residue deposit may produce differential effects on the insect complex (Flanders, 1941; Holloway and Young, 1943; DeBach and Bartlett, 1951).

Second, we can produce a selective action on a pest-parasite complex by treating only those areas where the pest-parasite ratio is unfavorable. This method is one of the bases of supervised control of the alfalfa caterpillar in California (Smith and Allen, 1954). Population levels of both the host caterpillar and its parasite, *Apanteles medicaginis* Muesebeck, are determined at appropriate intervals in all fields. A prediction of possible damage is made on the basis of these population levels, and only those infestations which are potentially damaging are treated. In this way, on an area-wide

basis, the balance is shifted in favor of the parasites, even though parasite adults and parasite larvae within the host caterpillars are often destroyed in the treated fields. The success of such programs will depend on the exact nature of the local problem and the quality of supervision. The rates of dispersal of parasites, predators, and pests are complicating factors.

Third, proper timing of insecticides can produce a selective action on the pest and natural-enemy complex (Ewart and DeBach, 1947; Michelbacher and Middlekauff, 1950; Bartlett and Ewart, 1951; Jeppson, Jesser, and Complin, 1953; Massee, 1954; DeBach, 1955). In such situations, an intimate knowledge of the behavior patterns of the pests and their natural enemies is required.

Fourth, nonselective materials with short residual action may be used if the beneficial forms can survive in a resistant stage or in an untreated reservoir area. Stern and van den Bosch (1959) have demonstrated that parasites of the spotted alfalfa aphid can survive nonselective treatments if they are in the more resistant pupal stage. DeBach (1958*a*) reports successful integration of biological and chemical control of purple scale on citrus where alternate pairs of tree rows were sprayed at 6-month intervals with a nonselective oil treatment.

For some pests a disease pathogen may be used as a selective insecticide (Steinhaus, 1954; 1956). For example, under supervised control in the Dos Palos area of California, the polyhedrosis virus affecting the alfalfa caterpillar has been used successfully either alone or in combination with a selective insecticide to avoid the use of a nonselective treatment. More recently, interest has developed in the commercial use of virulent strains of *Bacillus thuringiensis* Berliner, for the control of certain truck- and field-crop pests in California. The use of disease pathogens as selective insecticides is in its infancy, but can be expected to increase in importance with additional research (Steinhaus, 1951, 1957).

The ideal selective material is not one that eliminates all individuals of the pest species while leaving all of the natural enemies. Use of such a material would force the predators and parasites to leave the treated area or starve (Clausen, 1936; Flanders, 1940). The ideal material is one that shifts the balance back in favor of the natural enemies (Boyce, 1936; Ripper, 1944; Wigglesworth, 1945).

Future of Integrated Control. If our knowledge were adequate today to outline an ideal integrated control program for a crop now utilizing an intensive fixed spray program, it would not be possible to switch to such a program immediately. The effects of the previous treatments may last several years. In some instances, effective biological control no longer exists and would have to be reëstablished. This may be a slow process (DeBach, 1951; DeBach and Bartlett, 1951; Pickett and Patterson, 1953; and others).

It should be emphasized also that the development of integrated control is not a panacea that can be applied blindly to all situations, for it will not work if biotic mortality agents are inadequate or if low economic thresholds preclude utilizing biological control (Barnes, 1959). However, it has worked so well in some appropriate situations that there can be no doubt as to its enormous advantages and its promise for the future.

LITERATURE CITED

BALCH, R. E.
1958. Control of forest insects. Ann. Rev. Ent. 3:449–68.

BARNES, M. M.
1959. Deciduous fruit insects and their control. Ann. Rev. Ent. 4:343–62.

BARTLETT, B., and W. H. EWART
1951. Effect of parathion on parasites of *Coccus hesperidum*. Jour. Econ. Ent. 44: 344–347.

BARTLETT, B. R., and J. C. ORTEGA
1952. Relation between natural enemies and DDT-induced increases in frosted scale and other pests of walnuts. Jour. Econ. Ent. 45(5):783–85.

BOVEY, PAUL
1955. Les actions secondaires des traitements antiparasitaires sur les populations d'insectes et d'acariens nuisibles. Schweiz. Landw. Monatsh. 33 (9/10):369–79.

BOYCE, A. M.
1936. The citrus red mite, *Paratetranychus citri* McG. in California, and its control. Jour Econ. Ent. 29 (1):125–30.

BROWN, A. W. A.
1951. Insect control by chemicals. John Wiley & Sons, Inc., New York, N.Y. 817 pp.
1959. Spread of insecticide resistance. Adv. Pest Control Res. 2:351–414. Interscience Publishers, Inc., New York, N.Y.

CLAUSEN, C. P.
1936. Insect parasitism and biological control. Ent. Soc. Amer. Ann. 29:201–23.
1956. Biological control of insect pests in the continental United States. U.S. Dept. Agr. Tech. Bul. 1139. 151 pp.

CROW, J. F.
1957. Genetics of insect resistance to chemicals. Ann. Rev. Ent. 2:227–46.

DEBACH, P.
1951. The necessity for an ecological approach to pest control on citrus in California. Jour. Econ. Ent. 44(4):443–47.
1955. Validity of the insecticidal check method as a measure of the effectiveness of natural enemies of diaspine scale insects. Jour. Econ. Ent. 48(5):584–88.
1958*a*. Application of ecological information to control of citrus pests in California. Tenth Internatl. Congr. Ent. Proc. 3:185–97.
1958*b*. Selective breeding to improve adaptations of parasitic insects. Tenth Internatl. Congr. Ent. Proc. 4:759–67.

DEBACH, P., and B. BARTLETT
1951. Effects of insecticides on biological control of insect pests of citrus. Jour. Econ. Ent. 44(3):372–83.

DEBACH, P., C. A. FLESCHNER, and E. J. DIETRICK
1951. A biological check method for evaluating the effectiveness of entomophagous insects. Jour. Econ. Ent. 44(5):763–66.

DEBACH, P., J. H. LANDI, and E. B. WHITE
1955. Biological control of red scale. California Citrog. 40:254, 271–72, 274–75.

DECKER, G. C.
1958. Don't let the insects rule. Agr. Food Chem. 6(2):98–103.

DOUTT, R. L.
1958. Vice, virtue and the vedalia. Ent. Soc. Amer. Bul. 4(4):119–23.

DOUTT, R. L., and K. S. HAGEN
1950. Biological control measures applied against *Pseudococcus maritimus* on pears. Jour. Econ. Ent. 43 (1):94–96.

ELTON, CHARLES S.
1958. The ecology of invasions by animals and plants. 181 pp. Methuen & Co. Ltd., London; John Wiley & Sons Inc., New York, N.Y.

EWART, W. H., and P. DEBACH
1947. DDT for control of citrus thrips and citricola scale. California Citrog. 32:242–45.
FLANDERS, S. E.
1940. Environmental resistance to the establishment of parasitic Hymenoptera. Ent. Soc. Amer. Ann., 33:245–53.
1941. Dust as an inhibiting factor in the reproduction of insects. Jour. Econ. Ent. 34(3):470–1.
1945. Coincident infestations of *Aonidiella atrana* and *Coccus hesperidum*, a result of ant activity. Jour. Econ. Ent. 38:711–12.
FLESCHNER, C. A., and G. T. SCRIVEN
1957. Effects of soil-type and DDT on ovipositional response of *Chrysopa californica* (Coq.) on lemon trees. Jour. Econ. Ent. 50(2):221–22.
FORBES, S. A.
1880. On some interactions of organisms. Illinois State Lab. Nat. Hist. Bul. 3:3–17.
GLEN, R.
1954. Factors that affect insect abundance. Jour. Econ. Ent. 47:398–405.
GRIFFITHS, J. T.
1951. Possibilities for better citrus insect control through the study of the ecological effects of spray programs. Jour. Econ. Ent. 44:464–68.
GRISON, P., and E. BILIOTTI
1953. La signification agricole des "stations refuges" pour la faune entomologique. Acad. d'Agr. de France Compt. Rend. 39(2):106–9.
HAYES, W. J.
1954. Agricultural chemicals and public health. U. S. Public Health Reports 69(10): 893–98.
HERTZLER, J. O.
1956. The crisis in world population. 279 pp. Univ. Nebraska Press, Lincoln.
HOLLOWAY, J. K., and T. ROY YOUNG, JR.
1943. The influence of fungicidal sprays on entomogenous fungi and on the purple scale in Florida. Jour. Econ. Ent. 36(3):453–57.
HOSKINS, W. M., and H. T. GORDON
1956. Arthropod resistance to chemicals. Ann. Rev. Ent. 1:89–148.
HUFFAKER, C. B., and C. E. KENNETT
1956. Experimental studies on predation: Predation and cyclamen-mite populations on strawberries in California. Hilgardia 26(4):191–222.
JEPPSON, L. R., M. J. JESSER, and J. O. COMPLIN
1953. Timing of treatments for control of citrus red mite on orange trees in coastal districts of California. Jour. Econ. Ent. 46:10–14.
KLOSTERMEYER, E. C., and W. B. RASMUSSEN
1953. The effect of soil insecticide treatments on mite populations and damage. Jour. Econ. Ent. 46:910–12.
LINSLEY, E. G., editor
1956. Evaluation of certain acaricides and insecticides for effectiveness, residues, and influence on crop flavor. Hilgardia 26(1):1–106.
LORD, F. T.
1947 The influence of spray programs on the fauna of apple orchards in Nova Scotia: II. Oystershell scale, *Lepidosaphis ulmi* (L.) Canad. Ent. 79:196–209.
MASSEE, A. M.
1954. Problems arising from the use of insecticides: effect on the balance of animal populations. 6th Commonwealth Entomol. Conf. Rept. Pp. 53–57. London, England.
METCALF, R. L.
1955. Physiological basis for insect resistance. Physiol. Rev. 35:197–232.
MICHELBACHER, A. E.
1954. Natural control of insect pests. Jour. Econ. Ent. 47(1):192–94.

Michelbacher, A. E., and S. Hitchcock
1958. Induced increase of soft scales on walnut. Jour. Econ. Ent. **51**(4):427–31.

Michelbacher, A. E., and W. W. Middlekauff
1950. Control of the melon aphid in northern California. Jour. Econ. Ent. **43**(4): 444–47.

Painter, R. H.
1951. Insect resistance in crop plants. xi + 520 pp. Illus. Macmillan Company, New York, N.Y.

Petty, C. S.
1957. Organic phosphate insecticide poisoning; an agricultural occupational hazard. Louisiana St. Med. Soc. Jour. **109**(5):158–64.

Pickett, A. D.
1949. A critique on insect chemical control methods. Canad. Ent. **81**(3):67–76.

Pickett, A. D., and N. A. Patterson
1953. The influence of spray programs on the fauna of apple orchards in Nova Scotia. IV. A Review. Canad. Ent. **85**(12):472–78.

Pickett, A. D., W. L. Putman, and E. J. Le Roux
1958. Progress in harmonizing biological and chemical control of orchard pests in eastern Canada. Tenth Internatl. Congr. Ent. Proc. **3**:169–74.

Ripper, W. E.
1944. Biological control as a supplement to chemical control of insect pests. Nature **153**:448–52.
1956. Effect of pesticides on balance of arthropod populations. Ann. Rev. Ent. **1**:403–38.
1958. The place of contracting organizations and professional supervision in the application of pest control methods. Tenth Internatl. Congr. Ent. Proc. **3**:93–97.

Ripper, W. E., R. M. Greenslade, and G. S. Hartley
1951. Selective insecticides and biological control. Jour. Econ. Ent. **44**(4):448–59.

Robertson, J. G.
1957. Changes in resistance to DDT in *Macrocentrus ancylivorus* Rohw. Canad. Jour. Zool. **35**(5):629–633.

Sabrosky, C. W.
1952. How many insects are there? Pp. 1–7 *in:* Insects, 1952 Yearbook of Agriculture. 780 pp. U. S. Dept. Agr., Washington, D.C.

Schneider, F.
1955. Beziehungen zwischen nützlingen und chemischer Schädlingsbekämpfung. Deutsche Gesell. f. Angw. Ent. Verhandl. (13te Mitglied versamm.). **1955**:18–29.

Simmonds, F. J.
1956. The present status of biological control. Canad. Ent. **88**(9):553–63.

Smith, H. S., and P. DeBach
1953. Artificial infestation of plants with pest insects as an aid in biological control. Seventh Pacific Sci. Congr. Zoology (1949) Proc. **4**:255–59.

Smith, Ray F.
1959. The spread of the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), in California. Hilgardia **28**(21):647–91.

Smith, R. F., and W. W. Allen
1954. Insect control and the balance of nature. Sci. Amer. **190**(6):38–42.

Solomon, M. E.
1953. Insect population balance and chemical control of pests. Chem. and Indus. **1953**: 1143–47.

Steinhaus, E. A.
1951. Possible use of *Bacillus thuringiensis* Berliner as an aid in the biological control of the alfalfa caterpillar. Hilgardia **20**(18):359–81.
1954. The effects of disease on insect populations. Hilgardia **23**(9):197–261.
1956. Potentialities for microbial control of insects. Agr. Food Chem. **4**(8):676–80.
1957. Concerning the harmlessness of insect pathogens and the standardization of microbial control products. Jour. Econ. Ent. **50**(6): 715–20.

STEINHAUS, E. A., and C. G. THOMPSON
1949. Preliminary field tests using a polyhedrosis virus in the control of the alfalfa caterpillar. Jour. Econ. Ent. **42**(2):301–5.
STERN, V. M., and R. VAN DEN BOSCH
1959. Field experiments on the effects of insecticides. Hilgardia **29**(2):103–30.
STRICKLAND, A. H.
1954. The assessment of insect pest density in relation to crop losses. 6th Commonwealth Ent. Conf. Rept., pp. 78–83. London, England.
THOMAS, W. L., JR., EDITOR
1956. Man's role in changing the face of the earth. 1193 pp. Univ. Chicago Press, Chicago, Ill.
THOMPSON, C. G., and E. A. STEINHAUS
1950. Further tests using a polyhedrosis virus to control the alfalfa caterpillar. Hilgardia **19**(14):411–45.
TROUVELOT, B.
1936. Le doryphore de la pomme de terre (*Leptinotarsa decemlineata* Say) en Amerique de Nord. Ann. Epiphyt. (n.s.) **1**:277–336.
ULLYETT, G. C.
1947. Mortality factors in populations of *Plutella maculipennis* (Tineidae: Lep.) and their relation to the problem of control. South African Dept. Agr. and Forestry Ent. Mem. **2**(6):77–202.
1951. Insects, man and the environment. Jour. Econ. Ent. **44**(4):459–64.
UPHOLT, W. M.
1955. Evaluating hazards in pesticides use. Agr. Food Chem. **3**(12):1000–6.
WILLE, J. E.
1951. Biological control of certain cotton insects and the application of new organic insecticides in Peru. Jour. Econ. Ent. **44**:13–18.
WIGGLESWORTH, V. B.
1945. DDT and the balance of nature. Atlantic Monthly **176**(6):107–13.

FIELD EXPERIMENTS ON THE EFFECTS OF INSECTICIDES[1]

VERNON M. STERN AND ROBERT van den BOSCH

When the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), appeared in California in 1954, the state was faced with a serious agricultural problem, for this insect threatened the very existence of the great alfalfa industry. Alfalfa is a basic agricultural crop in California, with an annual planting of well over a million acres. It is the foundation of the state's tremendous dairy and livestock industry as well as the major source of seed for out-of-state consumers. Moreover, it is a key crop in the various crop rotation systems employed throughout the state.

Very quickly after the establishment of the aphid, research was initiated to find and develop alfalfa varieties resistant to aphid attack, and a search was undertaken in the Old World for parasites and predators of this newly introduced alfalfa pest. Simultaneously, an insecticide evaluation program was initiated to find materials which would control this new alfalfa pest at reasonable cost and also meet residue tolerance regulations on alfalfa hay.

In the emergency situation, parathion, malathion, and TEPP filled the requirements for the badly needed insecticides. There can be no doubt that even though these materials were not the final answer for chemical control of the aphid, they prevented widespread devastation to California's great alfalfa industry in the early months of the emergency.

Experimentation with insecticides did not end with the adoption of parathion and malathion as chemical control measures. Early investigations indicated that even though they gave excellent aphid control, they also appeared to be highly destructive to native natural enemies of the aphid, particularly coccinellids. This factor became strikingly evident at Hinkley, California, during the late summer of 1956 where it was found that the aphid had developed a low degree of resistance to certain organophosphorus insecticides (Stern and Reynolds, 1958). In surveying the area where resistance had developed and growers had repeatedly treated their fields, it was invariably found that natural enemies of the aphid had been largely eliminated by spray materials. This was an extremely alarming situation and clearly revealed the inherent danger in a pest control strategy in which total reliance was placed on chemicals, especially where the chemicals were of indiscriminate toxicity. In the absence of biological checks, the resistant aphids freely multiplied to tremendous numbers and caused severe damage to the alfalfa despite the frequent chemical treatments.

Analysis of the Hinkley situation clearly indicated an imperative need for an insecticide that would give adequate aphid control and also allow the native predators to survive treatment. In addition, the aphid parasites *Praon palitans* Mues., and *Trioxys utilis* Mues., brought into California from the Old World, had become established in several areas (van den Bosch, 1956, and van den Bosch, Schlinger, and Dietrick, 1957). Preliminary studies indicated both to be highly promising enemies of the aphid. If they were to attain their full potential as biological control factors

[1] Received for publication April 17, 1958.

against the aphid, they would also have to survive any necessary chemical treatment to a considerable degree. What was needed was a control program in which chemical and biological control would complement one another. In such a relation the native and introduced enemies surviving treatment would remain in the treated area to attack any aphids not killed by the insecticide application or those migrating into the field after the insecticide had broken down. The preservation of enemies of the aphid in the treated area would thus serve to prolong the effectiveness of the chemical. Parasites and predators of other insect pests would also survive treatment and continue to attack their hosts either in alfalfa or on other adjoining crops. Moreover, with increased chemical control on alfalfa, consideration had to be given to the possibility that the extensive use of the widely toxic insecticides, parathion and malathion, might cause resistance to develop in a wide variety of other insect pests frequently found in alfalfa fields, which, though not necessarily damaging to alfalfa, might become resistance problems in other crops.

Numerous compounds were evaluated in the research program to find a selective insecticide for aphid control. Many were never tested in the field because research on other crops strongly suggested they would never meet residue tolerance regulations on alfalfa hay. In addition, because of the small margin of profit per cutting of alfalfa, a number of compounds were discarded owing to their high cost. Eventually five materials, parathion, malathion, Trithion, Phosdrin and Systox, were selected for a thorough analysis of their effect on the aphid as well as on enemies of the aphid.

GENERAL EXPERIMENTAL METHODS

Alfalfa grown for hay (or seed) proved to be a highly desirable medium for testing the relative toxicities of insecticides to beneficial insects, for it is normally of uniform growth and is often inhabited by large populations of beneficial insects, which are relatively easy to sample. In the experiments a variety of designs, plot sizes, locations, insecticidal materials, and application methods were used.

The method of evaluating the effect of each compound on the aphid was the same in all tests. Single alfalfa stems were cut just above ground level and the living immature apterous and adult aphids on them were counted. In most tests, treatments were replicated 4 times in randomized plots and 25 alfalfa stems were examined in each replicate to give 100 stems per treatment. Effectiveness of a material or dosage was determined by the reduction of aphids in the treatments as compared with the untreated check.

Two sampling methods were used to determine the effect of the insecticides on beneficial insects, these being (1) counts of beneficial insects in square foot areas, and (2) counts of insects collected by sweeps of the standard insect sweeping net (handle, 26 inches long; hoop, 15 inches in diameter; Indian-Head cloth bag, 24 inches deep). The square foot sampling method was employed during cold weather (winter) when the alfalfa was short and the insects relatively inactive and sheltering near the ground. Sweep sampling was used during the warm months when the insects were

highly active in the vigorously growing alfalfa. In most cases, the beneficial insects were counted in the field at the time of sampling. When this was not possible, the samples from each replicate were emptied into pint ice cream cartons and brought into the laboratory under refrigeration and then counted.

With the exception of two airplane tests (nos. 6 and 8), all sprays were applied at a pressure of 60 pounds per square inch with a ground sprayer equipped with no. 4X hollow-cone nozzles arranged 18 inches apart for broadcast spraying.

PRELIMINARY STUDY

Early investigations by van den Bosch, Reynolds, and Dietrick (1956) showed parathion to be highly toxic to certain predacious insects in alfalfa. When the spotted alfalfa aphid developed a low degree of resistance to organophosphorus compounds at Hinkley, California, it was noticed that where parathion was repeatedly applied, the alfalfa fields were essentially barren of arthropods except resistant spotted alfalfa aphids and certain spiders. In addition, net sweeps taken during the summer of 1956 in parathion-treated fields showed that the complex of insects normally inhabiting alfalfa fields was drastically depleted. To carry these general observations further, a preliminary survey was made in the Mojave Desert to gather numerical data on the relative abundance of predators in a field repeatedly treated with parathion as compared with a field which had been untreated for about five months prior to sampling. The treated alfalfa field was sprayed twice by ground equipment during August, using 4 ounces of parathion per acre. It was treated twice in September and twice in October, using 6 ounces of parathion per acre. Before the survey was made, a number of moderate frosts occurred in the Mojave Desert which stunted growth of the alfalfa. This factor, plus retarded insect activity, made sweep sampling impractical. Thus, the relative abundance of beneficial insects in both fields was measured by sampling random square-foot areas as the

TABLE 1

RELATIVE ABUNDANCE OF PREDATORS IN A HEAVILY TREATED AND UNTREATED ALFALFA FIELD IN THE MOJAVE DESERT, CALIFORNIA, LATE OCTOBER, 1956

Ten square-foot samples were taken in each field

Sample field	Coccinellid spp.	*Geocoris* sp.	*Orius* sp.	Anthocorid sp.	*Collops* sp.	Average number of aphids per stem
	A* L	A N	A N	A N	A L	
Repeated parathion treatments‡	0—0	2—6	0—0	0—0	1—12	29
Untreated	66†—1	29—37	10—8	9—22	0—35	1.0

* A = adult; L = larva; N = nymph.

† A mixed population comprised of *Hippodamia convergens* Guèrin; *H. quinquesignata punctulata* LeConte; *H. parenthesis* (Say); and *H. sinuata* Mulsant.

‡ Treated twice by ground equipment in August (4 ounces of parathion per acre) and twice in both September and October (4 ounces per acre).

samplers moved diagonally across the fields. The aphids were sampled by cutting alfalfa stems and counting the aphids on them. The data are summarized in table 1.

The data in this table show that beneficial insect populations had been essentially eliminated in the field subjected to repeated parathion treatments whereas, by comparison, beneficial insects were quite abundant in the untreated field. Correspondingly, resistant aphids were 29 times as abundant in the treated field as in the untreated field. With this evidence from the preliminary survey, supported by the earlier knowledge of the indiscriminate toxicity of parathion and by field observations during the summer of 1956, it was apparent that when heavy repeated applications of parathion were made for aphid control, the alfalfa fields were literally defaunated. Under such conditions dispersing alate aphids could migrate into such biotic vacuums and reproduce explosively, leading to a treadmill of insecticidal treatment and eventual widespread resistance of the aphid to organophosphorus insecticides.

EXPERIMENTAL PROGAM

Test No. 1. Following the preliminary survey just discussed, an experimental program was undertaken to find a selective insecticide. The first of a series of field tests was conducted near Lancaster, on the western edge of the Mojave Desert, on November 17, 1956. This experiment was conducted to determine the effect of a number of insecticides on a heavy infestation of the spotted alfalfa aphid and a complex of associated coccinellid species. Each treatment was replicated five times, with each plot being 68 feet long and 30 feet wide. The alfalfa was 6 to 8 inches tall. Treatments were evaluated between 48 and 72 hours after application and on the sixth day after treatment. The data are summarized in table 2.

TABLE 2

GROUND-EQUIPMENT SPRAY TESTS OF THE TOXICITY OF SEVERAL INSECTICIDES TO ADULT COCCINELLIDS* IN ALFALFA NEAR LANCASTER, CALIFORNIA, ON NOVEMBER 17, 1956

15 square-foot samples per treatment

Material	Toxicant per acre	Coccinellids at 2 intervals after treatment					
		2–3 days			6 days		
		Number alive	Number dead	Per cent mortality	Number alive	Number dead	Per cent mortality
Parathion	8.2 oz.	4	58	94	92	140	60
Systox	6.2 oz.	42	44	51	92	51	36
Schradan	16.6 oz.	69	20	23	179	26	13
Pyrethrum†	1.6 pts.	73	24	25	204	21	9
Rotenone‡	1 qt.	111	20	15	139	22	14
Untreated	......	18	3	15	177	23	12

* A mixed population comprised of *Hippodamia convergens*, *H. quinquesignata punctulata*, *H. parenthesis*, and *H. sinuata*.

† By weight: pyrethrins 1.4%, mineral oil 23.6%, pine oil 45%.

‡ By weight: rotenone 2.5%, other cube resins 2.5%, ethylene glycol oleic esters 45%.

In the experimental field, because of the lateness of the season, the tips of the alfalfa had frozen, and the alfalfa cover was restricted to isolated clusters. Day temperatures were low and insect activity was restricted to a short period in midafternoon. In the brief warm period, the coccinellids would crawl from the litter and onto the alfalfa stems. There they would adjust themselves at right angles to the sun and feed on the spotted alfalfa aphid. As the temperature decreased, they would again crawl under the litter. Coccinellids were sampled by counting the live and dead adults within randomly selected square-foot areas. The first sample was started 48 hours after application and completed 72 hours after treatment. In sampling, a square-foot frame was cast at random using three such randomized subsamples in each replicate or a total of 15 samples per treatment. The disadvantage in casting the square frame was that it frequently landed between alfalfa clusters. In such cases, there were usually no lady beetles in the sample. This occurred quite often, particularly in the untreated plot on the first sampling period, which accounts for the low number of beetles in that sample. On the second sampling date, 6 days after application, the sampling method was changed somewhat so that if more than three fourths of the square-foot frame enclosed barren ground, the frame was recast. This tended to increase the numbers of lady beetles taken on the second sampling day. An additional increase may have been from some beetles migrating into the plots from an adjoining field where they had essentially eliminated the aphid food supply.

The data in table 2 show that parathion applied at 8.2 ounces per acre was more toxic to the coccinellids than Systox, schradan, pyrethrum, or rotenone. In comparison with tests conducted later in the investigations (summer, 1957) the relative toxicity of parathion to coccinellids in this test was not as high as when this material was applied at lower dosages. The reason for this difference appears to be that in the test under discussion,

TABLE 3

RESULTS OF SPRAY TESTS APPLIED BY GROUND EQUIPMENT FOR THE CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT LANCASTER, CALIFORNIA, NOVEMBER 17, 1956

Material	Amount per acre		Interval between treatment and sampling			
			2–3 days		6 days	
	Toxicant	Gallons	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot
Parathion	8.2 oz.	11.5	494	93	186	97
Systox	6.2 oz.	11.5	0	100	3	99
Schradan	16.2 oz.	11.5	582	92	318	94
Pyrethrum*	1.6 pts.	11.5	4,081	44	2,573	52
Rotenone†	1 qt.	11.5	4,292	42	2,850	47
Untreated	......	....	7,338	..	5,331	..

* By weight: pyrethrins 1.4%, mineral oil 23.6%, pine oil 45%.
† By weight: rotenone 2.5%, other cube resins 2.5%, ethylene glycol oleic esters 45%.

TABLE 4

RELATIVE TOXICITY OF VARIOUS INSECTICIDES APPLIED BY GROUND EQUIPMENT TO PREDATOR SPECIES IN ALFALFA AT THERMAL, CALIFORNIA, DECEMBER 3, 1956

Material and dosage per acre	Interval after treatment and number of predators per 200 sweeps													
	Coccinellids*		*Nabis* sp.		Syrphid spp.		*Orius* sp.		*Chrysopa* sp.		*Sinea* sp.		Field spiders	
	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.	24 hrs.	72 hrs.
	A† L	A L	A N	A N	A L	A L	A N	A N	A L	A L	A N	A N		
Parathion, 4.4 oz.	11—0	4—0	2—1	1—0	8—0	5—2	14—0	12—0	2—0	4—0	1—2	0—1	47	28
Systox, 2.5 oz.	29—8	17—23	43—6	16—4	5—2	10—0	103—0	43—1	173—3	42—3	5—35	0—10	69	40
Schradan, 6.9 oz.	38—9	30—11	31—6	8—2	17—12	18—18	83—1	38—2	216—0	34—3	3—10	2—1	47	22
Pyrethrum & rotenone,‡ 42.3 lbs.	29—10	21—11	20—3	4—0	5—11	16—22	12—0	11—0	68—1	26—0	3—14	3—2	32	42
Untreated	34—3	22—9	40—2	18—0	6—14	8—24	115—0	44—0	296—0	61—1	7—12	5—4	49	36

* Coccinellids were mainly *Hippodamia convergens.*
† A = adult; L = larva; N = nymph.
‡ The dust mixture consisted of pyrethrins 0.115%, rotenone 0.200% and MGK-264 0.400%. The balance was diluent with about 4% oil in the finished dust.

TABLE 5

EFFECTIVENESS OF VARIOUS INSECTICIDES APPLIED ON DECEMBER 3, 1956, BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT THERMAL, CALIFORNIA

Material	Amount per acre		Interval between treatment and sampling					
			1 day		3 days		8 days	
	Toxicant	Gallons	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot	Number of apterous aphids per 125 stems	Per cent reduction from untreated plot
Parathion	4.4 oz.	13.1	8,651	15	1,595	64	1,200	77
Systox	2.5 oz.	11.8	199	98	39	99	92	98
Schradan	6.9 oz.	10.4	9,680	4	2,910	34	3,247	38
Pyrethrum & rotenone*	42.3 lbs.	....	7,328	28	3,629	17	4,086	21
Untreated	......	....	10,122	..	4,381	..	5,204	..

* The dust mixture consisted of pyrethrins 0.115%, rotenone 0.200% and MGK-264 0.400%. The balance was diluent with about 4% oil in the finished dust.

many of the beetles were under the ground litter when the materials were applied and many probably did not crawl onto the plants and contact the toxic residue. Nevertheless, Systox applied at the heavy dosage of 6.2 ounces per acre had far less effect on the beetles than parathion, while schradan, pyrethrum, and rotenone had still less.

Aphid control in this test varied. The data are summarized in table 3. Systox applied at 6.2 ounces per acre essentially eliminated the aphids. Control with parathion and schradan was slightly less effective, while pyrethrum and rotenone gave mediocre control.

Test No. 2. On December 3, 1956, insecticides were applied by ground equipment on alfalfa at Thermal, California, in the Coachella Valley. This experiment was conducted to determine the relative toxicity of a number of insecticides to the spotted alfalfa aphid and to a variety of predator species in alfalfa. Three sprays and one dust mixture material were applied. The alfalfa was about 16 inches tall at time of treatment and each treatment was replicated five times. The effects of the materials on the predator species were evaluated 1 and 3 days after application by sampling with a standard insect net. Forty 180-degree sweeps were made in each replicate, or a total of 200 sweeps per treatment. The sweepings from each replicate were placed in pint ice cream cartons, brought into the laboratory and held at 35° F until counted the next day. The data are summarized in table 4.

Twenty-four hours after application, coccinellids, syrphids, *Nabis* sp., *Orius* sp., *Chrysopa* sp., and *Sinea* sp., were largely eliminated from the plots treated with 4.4 ounces of parathion. Systox, schradan, and the pyrethrum-rotenone dust mixture were far less toxic to the predators. Seventy-two hours after treatment, the predator populations were still very low in the parathion plots. On the other hand, Systox applied at 2.5 ounces per acre caused little or no reduction in predators (except syrphids) in comparison with the untreated plots.

The effects of the materials on the aphid were evaluated 1, 3, and 8 days after application. The data are summarized in table 5. Twenty-four hours after treatment, Systox applied at 2.5 ounces per acre gave satisfactory aphid mortality. Results were very poor where parathion, schradan, and the pyrethrum-rotenone dust mixture were applied. The Coachella Valley is an area where the aphid had developed a low degree of resistance to organophosphorus compounds (Stern and Reynolds, 1958), which accounts for the mediocre kill with parathion. Even though schradan and the pyrethrum-rotenone dust mixture were relatively nontoxic to beneficial insects, further evaluation of these materials was discontinued because of their mediocre effect on the aphid in the test under discussion. It may be noted that in test no. 1, at Lancaster, schradan gave satisfactory aphid mortality when applied at 16.2 ounces per acre. However, the cost of treatment at this dosage would be prohibitive on alfalfa hay.

Test No. 3. After analyzing the data from Lancaster (test no. 1) and Thermal (test no. 2), it seemed evident that Systox was far less toxic to beneficial insects than parathion. The Thermal experiment and the work of Reynolds and Anderson (1955) and Bieberdorf and Bryan (1956) showed that Systox gave satisfactory aphid control when applied at 2 to 4

TABLE 6

EFFECTIVENESS OF VARIOUS INSECTICIDES APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT HEMET, CALIFORNIA, ON FEBRUARY 5, 1957

Material	Amount per acre		Interval between treatment and sampling					
			1 day		3 days		7 days	
	Toxicant	Gallons	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot
Systox	0.9 oz.	13.7	18	99	3	99	10	99
Systox	1.4 oz.	11.1	7	99	0	99	11	99
Parathion	3.1 oz.	12.5	95	99	10	99	31	99
Sevin	10.8 oz.	16.1	5,019	67	698	94	312	96
C-140*	10.4 oz.	12.5	6,243	59	1,255	88	140	98
Untreated	......	....	15,044	..	10,817	..	6,869	..

* Hydrochloride salt of the dimethylcarbamate of *o*-dimethylaminophenol (C-140 of Rohm and Haas Co.).

ounces per acre by ground equipment. At this dosage, however, the prospect of using Systox on alfalfa was not bright because of its high cost as compared with the other materials then registered for use against the spotted alfalfa aphid. Therefore, the dosage had to be reduced if this promising material was to be brought into the spotted-alfalfa-aphid control picture. Accordingly, a preliminary test using Systox at low dosages (0.9 and 1.4 ounces per acre) was conducted on alfalfa at Hemet, California, on February 5, 1957. A variety of materials in addition to Systox were also tested on this date. The alfalfa was about 10 inches tall and the treatments were replicated four times. Each replicate was 90 feet long and 30 feet wide. The materials were evaluated 1, 3, and 7 days after application. The data are summarized in table 6.

Systox was applied at two dosages, 0.9 and 1.4 ounces per acre, and both gave 99 per cent aphid mortality 1 day after application. Parathion, used as a standard comparison material and applied at 3.1 ounces per acre also gave 99 per cent mortality 1 day after treatment. There was little if any alate aphid dispersal in the area during the testing period and the excellent control with Systox and parathion continued throughout the experiment. Aphid mortality with Sevin and C-140 (the hydrochloride salt of the dimethyl-carbamate of *o*-dimethylaminophenol) was mediocre 24 hours after application. But by the third day after application the aphids had decreased greatly in both of these treatments and 7 days after application the populations were at low levels. The number of aphids in the untreated plots also decreased during the same period, however, and thus the aphid reduction in the plots treated with Sevin and C-140 may have been only partially due to the effects of the compounds.

Following the very promising performance of the low dosage of Systox in the Hemet test, another experiment was conducted at Calipatria, Imperial County, California. In this test, Systox was applied at 0.4 and 0.9 ounce per acre. Parathion, used as a standard comparison material, was applied at 4.2 ounces per acre. Both dosages of Systox and the parathion gave satisfactory control 24 hours after application.

Test No. 4. During the course of the investigations, two promising new materials, Trithion and Phosdrin, had been tested for aphid control (Stern and Reynolds, 1957) and were registered for use on alfalfa hay or seed in California. Since the relative toxicities to beneficial insects of these materials and also of malathion were not known, it was necessary to include them in a series of comparisons with Systox. Accordingly, on March 28, 1957, the first of a series of such experiments was conducted at Hinkley, California, in the Mojave Desert. Sprays were applied by ground rig when the alfalfa was about 18 inches tall. Each treatment was replicated four times. Each replicate was 325 feet long and 30 feet wide. To test the effect of the materials on beneficial insects, the plots were sampled with a standard sweep net 10 minutes after application and at 24 and 48 hours after treatment. The 10-minute posttreatment sample was made to determine whether predators suffered quick knockdown or whether the insecticides had a repellent effect on the adults. In all samples, 30 sweeps were taken in each replicate or a total of 120 sweeps per treatment. The first samples taken 10

TABLE 7

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO BENEFICIAL INSECTS IN ALFALFA AT HINKLEY, CALIFORNIA, IN THE MOJAVE DESERT, MARCH 28, 1957

Material	Toxicant per acre	Number of live and dead predators recorded 8 hours after treatment from 120 sweep samples taken 10 minutes after application									
		Coccinellids		*Nabis* sp.		*Geocoris* sp.		Syrphids		*Chrysopa* sp., adults	*Orius* sp., adults
		Adults	Larvae	Adults	Nymphs	Adults	Nymphs	Adults	Larvae		
		D* L	D L	D L	D L	D L	D L	D L	D L	D L	D L
Malathion	9.5 oz.	101—0	13—0	2—1	0—6	4—5	0—1	0—0	9—5	2—0	1—0
Parathion	3.8 oz.	129—0	13—2	2—0	0—3	1—4	1—1	0—0	7—0	6—0	1—0
Trithion	11.6 oz.	74—46	15—26	0—7	0—2	5—4	0—0	2—2	3—3	4—1	0—0
Phosdrin	1.0 oz.	33†—0	25—0	10—0	1—4	3—1	0—0	0—0	11—3	5—0	0—0
Systox	0.7 oz.	9—119	1—49	0—21	0—6	0—5	0—1	0—0	0—2	0—3	3—10
Systox	1.5 oz.	9—106	3—43	0—17	0—18	0—6	0—2	1—0	1—7	1—4	2—11
Untreated	......	0—161	0—55	0—26	0—29	0—7	0—1	0—0	0—12	0—5	0—14

* D = dead; L = live.
† Adults are killed instantly, which accounts for the relatively low numbers of coccinellids swept 10 minutes after application.

TABLE 8

RELATIVE TOXICITY OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUPMENT TO BENEFICIAL INSECTS IN ALFALFA AT HINKLEY, CALIFORNIA, MARCH 28, 1957

Material	Toxicant per acre	Interval between treatment and sampling and number of predators per 120 sweeps											
		Coccinellids		*Nabis* sp.		*Geocoris* sp.		Syrphids		*Chrysopa* sp.		*Orius* sp.	
		24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.
		A* L	A L	A N	A N	A N	A N	A L	A L	A	A	A	A
Malathion	9.5 oz.	3—0	5—0	1—0	0—1	0—1	0—0	2—0	0—1	0	0	0	0
Parathion	3.8 oz.	5—0	4—1	0—0	1—0	0—0	0—0	2—0	0—0	0	0	0	0
Trithion	11.6 oz.	1—2	1—2	0—0	3—0	0—0	1—0	0—2	1—1	0	1	0	2
Phosdrin	1.0 oz.	14—0	14—0	0—0	0—0	1—0	1—0	1—0	0—2	1	0	0	2
Systox	0.7 oz.	18—6	12—8	2—3	2—1	1—1	0—0	1—1	0—0	3	4	4	6
Systox	1.5 oz.	22—20	10—14	5—2	2—3	1—0	0—0	4—1	1—1	1	3	8	6
Untreated	......	36—19	16—33	6—2	2—3	1—0	0—0	2—5	1—7	1	3	9	6

* A = adults; L = larva; N = nymph.

minutes after each specific material was applied were placed in pint ice cream cartons and brought into the laboratory. The loose alfalfa leaves, tips and other debris were taken out of the net before placing the insects in the cartons. One or two untreated alfalfa sprigs were then placed in each carton which was then covered with cotton gauze.

The untreated plot was sampled near the middle of the treatment schedule. Treatments were started at 10 o'clock in the morning. Malathion was first applied and sampled, and then parathion, Phosdrin, Trithion, and the low and high dosages of Systox were applied and sampled. The untreated plots were sampled after the Trithion treatment and sampling. The last treatment, the high dosage of Systox, was applied at 12:30 p.m. The 10-minute samples were brought into the laboratory and examined 8 hours after treatment, at which time the number of living and dead predators was recorded. The summarized data are shown in table 7.

Parathion, malathion and Phosdrin applied at 3.8, 9.5 and 1 ounce per acre, respectively, had killed essentially all the coccinellid adults and larvae when the 10-minute sweep samples were recorded 8 hours after application. It is interesting to note that a small sample of adult coccinellids was taken where Phosdrin was applied, the reason being that this material gives a near instantaneous knockdown of the lady-beetle adults. The high susceptibility of coccinellids to Phosdrin was noticed in earlier tests when this material was being evaluated for spotted alfalfa aphid control. High mortality of adult *Chrysopa* sp. and *Nabis* sp. occurred in the malathion, parathion and Phosdrin treatments. In addition, low numbers of adult and nymphal *Nabis* sp. were collected where these three materials were applied in comparison with the check. *Orius* adults and *Nabis* adults and nymphs were also collected in low numbers where Trithion was applied at 11.6 ounces per acre, which suggests a rapid knockdown of these species. Samples of coccinellids taken from the Systox treatments (0.7 and 1.5 ounces per acre) were lower than those taken from the untreated plots but of the coccinellids collected nearly all were alive when the 10-minute samples were observed and recorded 8 hours after application.

Trithion, one of the new materials applied at a higher dosage than required to control nonresistant aphids, caused moderate mortality of coccinellid adults and larvae, *Geocorus* adults, and syrphid adults and larvae. However, samples taken 24 and 48 hours after application in this and in subsequent tests show that Trithion is quite toxic to beneficial insects when applied at dosages of 7.3 ounces per acre and above, but the material apparently requires at least 24 hours before its effects are fully realized.

The plots were next sampled for the relative abundance of predators 24 and 48 hours after application. On these two days, a strong cold wind was blowing, a frequent occurrence in the Mojave Desert during the spring. This accounts for the low numbers of predators obtained as compared with the 10-minute sample on the day of application. The summarized data from the 24- and 48-hour sample appear in table 8.

Twenty-four hours after application, parathion, malathion, Trithion, and Phosdrin applied at 3.8, 9.5, 11.6 and 1 ounce per acre, respectively, had virtually eliminated the entire complex of entomophagous species. By

comparison, the beneficial species were still abundant in the two Systox treatments (0.7 and 1.5 ounces per acre) and in the untreated plot. Moreover, only a few miscellaneous insects and spiders were collected in the sweepings taken from the plots treated by the four widely toxic materials, particularly parathion and malathion.

In the plots treated with Phosdrin a number of adult lady beetles were collected. Phosdrin is a highly unstable compound and its toxic action is quickly lost. Insects migrating into the treated area a short while after application appear to be unharmed. The area concerned in this experiment was small and adjacent to large untreated areas. It is probable that the adult coccinellids swept in the Phosdrin plots 24 and 48 hours after application had migrated in soon after application. If, as a later test shows, Phosdrin is applied over a wide area, beneficial insects are reëstablished far less rapidly.

Systox appeared to eliminate a moderate number of the coccinellid adults but the larvae survived in greater numbers. This material appeared to have little effect on the other predators in the experimental area. In this and in another test, the lower dosage of Systox appeared to be more toxic to coccinellids than the higher dosage. This is felt to be a reflection of plot or sampling variation, there probably being no great difference in mortality between 1 and 1.5 or 2 ounces per acre.

In addition to testing the effect of the various materials on beneficial insects, the sprays were tested for their effect on the aphid, the main interest being in the effectiveness of the low dosages of Systox. The data are summarized in table 9.

Aphid populations at Hinkley, California, are resistant and the materials had a variable effect on the aphid. Twenty-four hours after application, malathion, Phosdrin, and the low and high dosage of Systox applied at 9.5, 1, 0.7 and 1.5 ounces per acre, respectively, gave satisfactory aphid mortality. Parathion and Trithion applied at 3.8 and 11.6 ounces per acre,

TABLE 9

EFFECTIVENESS OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT HINKLEY, CALIFORNIA, MARCH 28, 1957

Materia	Amount per acre		Interval between treatment and sampling			
			1 day		4 days	
	Toxicant	Gallons	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot
Malathion	9.5 oz.	11.4	18	98	35	98
Parathion	3.8 oz.	11.4	500	73	218	87
Trithion	11.6 oz.	11.6	651	64	194	88
Phosdrin	1.0 oz.	11.6	1	99	3	99
Systox	0.7 oz.	11.4	32	98	109	93
Systox	1.5 oz.	11.9	1	99	8	99
Untreated	......	....	1,822	..	1,664	..

TABLE 10

RELATIVE TOXICITY OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO A NUMBER OF PREDATORS AND TWO SPOTTED ALFALFA APHID PARASITES IN ALFALFA AT THERMAL, CALIFORNIA, APRIL 10, 1957

Treatment and dosage per acre	Interval between treatment and sampling and number of predators and aphid parasites per 100 sweeps																	
	Coccinellids			*Praon palitans*			*Trioxys utilis*			*Orius* sp.			*Nabis* sp.			*Chrysopa* sp.		
	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days	1 day	2 days	9 days
	A* L	A L	A L	A	A	A	A	A	A	A N	A N	A N	A N	A N	A N	A L	A L	A L
Malathion, 9.1 oz.	13—1	4- 2	98- 2	0	2	5	0	2	174	22—1	34—0	266—0	2—3	21—3	18- 2	0—0	0—0	7 -0
Parathion, 4.0 oz.	14—1	17 0	113- 33	1	0	4	3	1	227	37- 2	55- 0	307—0	1- 1	1—0	9- 0	1—0	1- 0	4—0
Phosdrin, 0.7 oz.	16 -3	10 -4	93- 255	3	2	4	0	8	202	115—1	99- 0	348—0	8—3	18—4	14- 0	1—1	4- 0	9—1
Trithion, 7.3 oz.	37 17	47- 0	58- 91	0	3	3	0	8	148	218—2	175- 0	272—0	10- 1	36—5	8 · 0	12—0	11- 1	10—0
Systox, 0.5 oz.	42—48	97—79	69—344	6	1	2	4	10	67	391—3	206- 0	142—0	12—0	25—0	12- 0	7—0	22- 1	6- 0
Systox, 0.9 oz.	38 -42	45- 74	38- 504	9	3	2	3	13	60	402—1	215 - 0	250—0	8- 2	26—5	14—0	2—0	16—0	5- 0
Check	78 54	385- 210†	114- 238	8	8	0	11	21	140	348—1	285—0	155—0	12- 1	32- 6	17—0	7—1	28—5	8- 0

* A = adult; L = larva; N = nymph.
† Sample number is far greater than would be expected. Unquestionably an inadvertent error was made in counting or in recording the data.

respectively, gave poor kills. Four days after application, control decreased slightly where 0.7 ounce of Systox was applied. When the first sample was taken, one day after treatment, most of the aphids remaining in the low dosage Systox plots were apterous adults. These adults continued to reproduce and small colonies of first-instar nymphs accounted for most of the aphids taken 4 days after application.

Test No. 5. On April 10, 1957, sprays were applied by ground equipment on alfalfa at Thermal in the Coachella Valley, California. This experiment was conducted to determine the effects of parathion, malathion, Phosdrin, Trithion, and Systox on beneficial insects. The alfalfa was about 14 inches tall and each treatment was replicated four times. Each replicate was 300 feet long and 30 feet wide. The effects of the materials on beneficial insects were evaluated 1, 2, and 9 days after application. A standard sweep net was used to sample the beneficial insects. Twenty-five sweeps were taken in each replicate, or 100 sweeps per treatment. The data are summarized in table 10. It was not possible to count the various predators and parasites in the field at the time of sampling so the sweepings were placed in pint ice cream cartons and brought into the laboratory for counting and recording.

Twenty-four hours after application nearly all the coccinellid larvae were eliminated by parathion, malathion, and Phosdrin applied at 4, 9.1 and 0.7 ounce per acre, respectively. These materials were not quite as toxic to the adult lady beetles as to the larvae, although the adults were drastically reduced in comparison with the untreated plots. Trithion applied at 7.3 ounces per acre reduced the adult coccinellids by about 50 per cent and the larvae by approximately 66 per cent, 24 hours after application. Systox applied at 0.5 and 0.9 ounce per acre gave a comparable reduction in lady-beetle adults, whereas the larvae were only slightly, if at all, reduced.

The numbers of coccinellids swept from the treatments cannot be directly compared with those from the untreated plots 48 hours after application, since there appears to have been an inadvertent error in counting or recording the 48-hour coccinellid sample from the untreated plots. The recorded data show that the adults increased five-fold and the larvae four-fold in the 24-hour period between the first and second sampling. It is felt that such an increase in adults and larvae is far greater than would be expected. There were numerous egg masses in all plots but it does not seem likely that there would be such a large hatch in lady beetle larvae or adult emergence or migration in a 24-hour period.

Comparing the 48-hour samples from the treated plots with their corresponding 24-hour samples, there were very low numbers of coccinellids where parathion, malathion, and Phosdrin were used. The number of adult coccinellids in the 48-hour sample was similar to the 24-hour sample where Trithion was used, whereas the larvae appeared to be eliminated 48 hours after application. Eggs were hatching and the number of larvae increased in the second sample where both dosages of Systox were used. The adults increased in the low dosage of Systox (0.5 ounce per acre) and remained more or less the same at the higher dosage.

Nine days after application, larvae in the Phosdrin and Systox plots had increased and exceeded the number swept from the untreated plots. As mentioned earlier, Phosdrin has a high initial toxicity to coccinellid adults and larvae. However, the material breaks down rapidly and in this instance, where there were numerous egg masses in the plots at time of treatment, the hatching larvae appear to have been unharmed. Malathion, parathion, and Trithion all have residual toxicity and apparently kill the young lady-beetle larvae as they emerge from the eggs. Thus where these three materials were applied, the numbers of larvae in the respective samples remained markedly lower than in the untreated plots 9 days after application. There appeared to be little difference between the numbers of lady-beetle adults in the malathion, parathion, Phosdrin, and untreated plots 9 days after application. Again, as in the previously discussed experiment, the experimental area adjoined a number of large untreated alfalfa fields and immigration of adult coccinellids obscured the initial mortality differences 9 days after application.

Twenty-four hours after application, the aphid parasites *Praon palitans* Mues. and *Trioxys utilis* Mues., and also *Orius*, *Nabis*, and *Chrysopa* were markedly reduced where parathion, malathion, and Phosdrin were used. Trithion appeared to be equally toxic to the aphid parasites but was less toxic to *Orius*, *Nabis*, and *Chrysopa* than the three materials mentioned above. In general, of the materials used in this test, Systox was by far the least toxic to beneficial insects. Nine days after treatment, the harmful effects to the beneficial insects from parathion, malathion, Phosdrin, and Trithion had largely disappeared. With the exception of coccinellid larvae, however, very few immature stages of other insects appeared in any of the samples. Thus, the reëstablishment of the beneficial insects could only have occurred by immigration from the large untreated areas adjoining the small test plots. Had the test plots been several acres in size, it is felt that the reëstablishment of the predators and parasites would have required a considerably longer period of time. Under such conditions, as discussed below, the use of either parathion, malathion, or Trithion over a wide area might have resulted in a rapid flareback of the aphid.

In testing the effect of the materials on the aphid, samples were taken 2, 5, 8, and 25 days after treatment. The data are summarized in table 11.

When the materials were evaluated 2 days after treatment, control was highly unsatisfactory for all materials. This reflects the resistance of the aphid population at Thermal to organophosphorus materials (Stern and Reynolds, 1958). Phosdrin, malathion, and the high dosage of Systox (0.9 ounce per acre) were applied at dosage levels which quickly kill nonresistant aphids, while parathion and Trithion were applied at rates in excess of dosages required to give a quick kill of nonresistant aphids. The lower dosage of Systox used in this experiment (0.5 ounce per acre) was probably close to the limit of toxic effect of this material, even for nonresistant aphids.

In following the trends of the resistant aphid populations in the various treatments, the effects of the insecticides on the beneficial insects must be considered, particularly their effect on coccinellids, since they are the pri-

TABLE 11

EFFECTIVENESS OF VARIOUS INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT FOR CONTROL OF THE SPOTTED ALFALFA APHID ON ALFALFA AT THERMAL, CALIFORNIA, APRIL 10, 1957

Material	Amount per acre		Interval between treatment and sampling						
			2 days		5 days		8 days		25 days
	Ounces of toxicant	Gallons of water	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems	Per cent reduction from untreated plot	Number of apterous aphids per 100 stems
Malathion	9.1	10.9	638	88	1,387	82	2,589	64	11
Parathion	4.0	12.1	1,050	80	1,874	75	2,608	64	9
Phosdrin	0.7	11.7	630	88	1,272	82	1,168	84	6
Trithion	7.3	10.9	1,677	68	3,566	54	3,190	56	9
Systox	0.5	11.1	1,693	68	2,620	66	1,746	76	15
Systox	0.9	10.9	1,426	73	1,678	78	1,141	84	7
Check	....	....	5,268	..	7,793	..	7,280	..	10

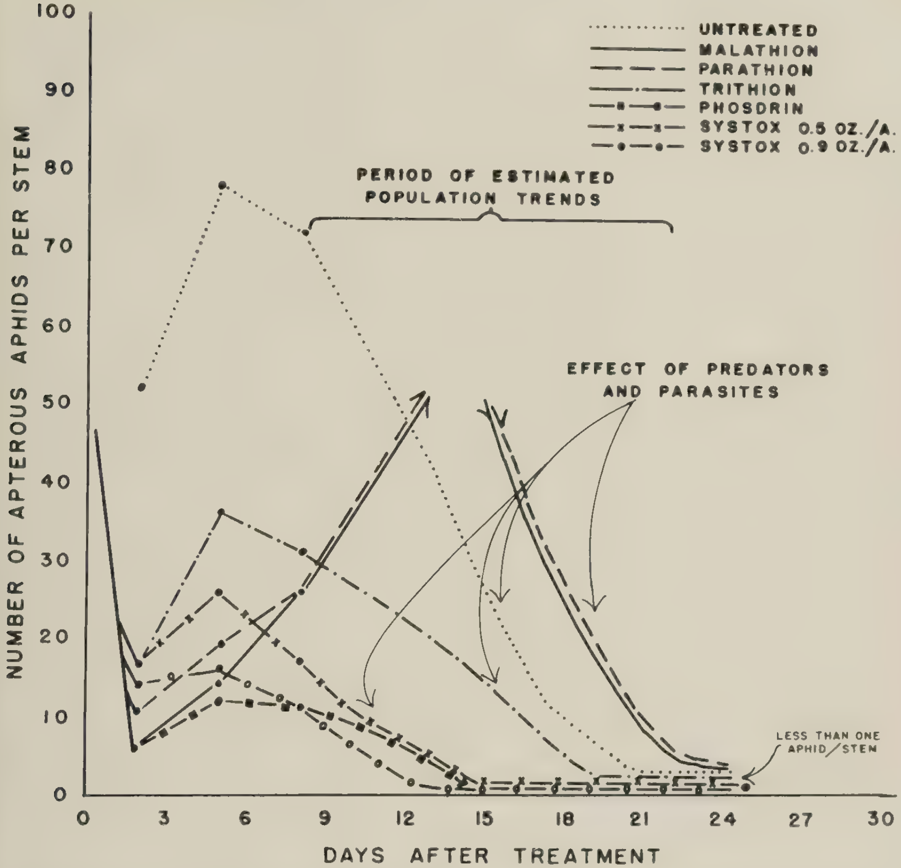


Fig. 1. Actual and estimated population trends of resistant spotted alfalfa aphid after treatment with various insecticides with different effects on beneficial insects; at Thermal, California.

mary aphid predators. The aphid population trends for the various insecticides appear in figure 1. Malathion, parathion, and Trithion were highly toxic to both immature and adult coccinellids. When the last sample for beneficial insects was taken 9 days after application, the lady-beetle populations were still low in these treatments. A characteristic of resistant aphids is that they continue reproduction after insecticide application. Thus, through the elimination of the coccinellids, the mature aphids surviving treatment continued to reproduce uninhibited by natural checks; and control decreased between the 2- and 5-day samples. Eight days after application, control decreased further where parathion and malathion were applied. On this day, aphid populations in the plots treated with parathion, malathion, and Trithion were all above the economic threshold. Where parathion and malathion were applied, the aphid population levels unquestionably increased to an even higher level before coccinellids reëstablished themselves and eventually eliminated the aphids. Unfortunately, samples

were not taken at an intermediate date between the eighth and twenty-fifth day after treatment. However, the malathion and parathion treaments could be distinguished from the others by the damaged alfalfa.

In the Phosdrin plots, control decreased between the second day and fifth day samples but did not show a further decline on the eighth day. Apparently, the short-lived Phosdrin had broken down sufficiently to permit the hatching coccinellid larvae and immigrating adults to survive. Nine days after treatment, the coccinellid population in the Phosdrin plots had reached a level comparable to the untreated areas. The coccinellids in the Phosdrin plots obviously started to increase before the ninth day and had apparently checked the increase in aphids on or about the eighth day after application.

Where the low dosage of Systox (0.5 ounce per acre) was applied, the per cent control decreased slightly between the 2-day and 5-day samples but increased between the 5- and 8-day sampling period. Mortality to coccinellids was moderate at the low dosage of Systox. Where 0.9 ounce per acre of Systox was applied, the percentage control increased throughout the sampling period.

Twenty-five days after application, beneficial insects had essentially eliminated the aphids from all the plots. Although the aphid population was not sampled between the eighth and twenty-fifth day after application, the trends of the aphid in the various treatments can be followed with reasonable accuracy by using the combined data from the aphid and beneficial insect samples. In the Systox plots, the resistant aphids were probably eliminated soon after the 9-day sample was taken. Also, after the 9-day sample, the biotic checks slowly increased to a point where they overtook and eventually destroyed the resistant aphids in the parathion, malathion, and Trithion plots. However, it must be remembered that these were very small plots, and had the plots been extensive in size or had the parathion, malathion, and Trithion been applied in isolated areas where immigration of coccinellids was not a factor, control would have been of short duration. Even in the favorable circumstances of small plots the alfalfa was severely damaged where parathion and malthion were applied.

One point that warrants emphasis is that the increase in dosage of pesticides of indiscriminate toxicity in the early stages of arthropod resistance apparently not only hastens increased resistance directly through selection but also indirectly through elimination of natural enemies which would otherwise help destroy surviving resistant individuals. With the elimination of biological checks, the pest species is essentially free to increase to greater density, which further increases the frequency of the resistant gene or gene combination. The density level of the resistant population will be determined by the physical factors in the environment and host-plant resistance. The release of population reproduction potential nearly always results in severe damage or economic stress in the specific locality of the resistant arthropod.

Test No. 6. On April 11, 1957, 1- and 2-ounce dosages of Systox were applied in 5 gallons of water per acre by aircraft to alfalfa at Thermal in the Coachella Valley. The experiment was conducted to test the effective-

ness of low dosages of Systox in commercial-sized blocks on the aphid and on coccinellids. Each treatment was replicated four times on alfalfa about 14 inches tall. The plots were 160 feet wide and 1,300 feet long. Pretreatment counts of the aphids and coccinellids were taken, but since this field was heavily infested with aphids at the time of treatment, it was not possible to leave untreated checks. The data obtained in the experiment are summarized in table 12.

TABLE 12

APHID AND COCCINELLID POPULATION TRENDS FOLLOWING TREATMENT WITH SYSTOX SPRAYS BY AIRPLANE AT THERMAL, CALIFORNIA, APRIL 11, 1957

Material	Toxicant per acre	Number of aphids per stem, pretreatment	Interval between treatment and sampling: 24 hrs.	4 days	7 days	25 days
			Average number of aphids per stem			
Systox	1 oz.	74	23	24	12	<1
Systox	2 oz.		7	8	3	<1
		Number of coccinellids per 100 sweeps, pretreatment	Number of coccinellids per 100 sweeps			
		A* L	A L	A L	A L	A L
Systox	1 oz.	144—92	57—141	53—463	26—276	108—5
Systox	2 oz.		52—158	35—599	12—214	127—5

* A = adult; L = larva.

Both dosages of Systox (1 and 2 ounces per acre) gave an approximate 62 per cent reduction in lady-beetle adults 24 hours after application. The reduction in lady beetles in this test appeared to be higher than in other Systox tests. The sample was taken late in the afternoon, which may have resulted in the lower numbers of beetles or it may be that the adults feeding on the resistant aphids sprayed with Systox ingested sufficient quantities of the toxicant to kill the more susceptible ones. Ahmed *et al.* (1954) demonstrated this phenomenon in laboratory tests with *Hippodamia convergens*.

There was an increase in coccinellid larvae between the pretreatment sample and the 24-hour sample. Egg masses were rather numerous in the field and a certain number of these hatched between the two sample dates. Thus, it is not possible to determine larval mortality due to the Systox applications. But results of other tests show Systox to be relatively nontoxic to coccinellid larvae and therefore mortality was probably low.

Immediately after application, coccinellid egg masses were collected and brought into the laboratory to determine the effects of Systox on the eggs. There was no inhibition of hatch in these egg samples.

Twenty-four hours after application, the resistant aphids were reduced by approximately 69 per cent where 1 ounce of Systox per acre was applied

TABLE 13

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED BY GROUND EQUIPMENT TO THE APHID PARASITE *Praon palitans* AND SEVERAL PREDATORS IN ALFALFA NEAR BAKERSFIELD, CALIFORNIA, JUNE 4, 1957

Interval between treatment and sampling and number of parasites and predators per 100 sweeps

Treatment and dosage per acre	*Praon palitans*			Coccinellids			*Nabis* sp.			*Orius* sp.			*Collops* sp.		
	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.	5 hrs.	24 hrs.	72 hrs.
				A* L	A L	A L	A N	A N	A N						
Parathion, 3.0 oz....	11	108	410	14—0	6—0	8—0	5—20	1—6	5—5	17	23	67	11	2	7
Malathion, 9.7 oz....	10	147	364	12—0	11—0	7—0	25—64	11—22	26—21	22	19	61	11	7	6
Phosdrin, 1.0 oz.....	39	206	397	12—1	13—0	20—0	18—39	13—18	28—22	49	36	108	18	10	13
Trithion, 5.0 oz.....	39	253	586	53—3	15—0	15—1	26 59	14—25	26 31	47	34	76	20	9	14
Systox, 1.0 oz.......	76	265	472	52—3	21—2	12—0	53—68	15—32	23—18	104	75	163	21	8	14
Systox, 2.0 oz.......	126	318	473	60 2	29—4	14—0	45—82	25—27	30 32	149	91	100	17	8	10
Untreated..........	384	331	629	71—16	54—12	52—10	48—65	22—38	21—24	188	116	166	18	8	12

* A = adult; L = larva; N = nymph.

and by approximately 91 per cent where 2 ounces of Systox per acre were used. On the fourth day, there was no apparent change in the aphid population, whereas the hatching of coccinellid egg masses greatly increased the lady-beetle larval population during the same interval. Seven days after treatment, the aphids had decreased sharply, being about 50 per cent below the levels of the fourth day in both treatments. Large numbers of the coccinellid larvae pupated and the larval population also decreased simultaneously. In some instances, there were 3 or 4 coccinellid pupae on single alfalfa stems. Twenty-five days after treatment, the resistant aphids surviving treatment and their resistant offspring were essentially eliminated from the plots because of the predation of coccinellids surviving the Systox spray applications. A significant feature of this experiment is that in this case 99 per cent initial mortality of the pest insect was not necessary for satisfactory control because sufficient predators remained after treatment to reduce and hold the pest population below the economic threshold. Thus, on this resistant population where neither chemical control nor biological control by itself was able to prevent damage to the crop, the two together acted as perfect complements and gave complete control.

Test No. 7. By late spring 1957, a considerable amount of data had been obtained showing the advantages of Systox over certain other organophosphorus compounds in control of the spotted alfalfa aphid. Test no. 5, at Thermal in the Coachella Valley, had given some evidence of the relative toxicity of parathion, malathion, Phosdrin, Trithion, and Systox to the newly introduced aphid parasites *Praon palitans* and *Trioxys utilis*. However, at Thermal the parasite populations were low and another test was needed on heavier parasite populations to clarify this picture. *P. palitans* had become well established in the southern end of the San Joaquin Valley during the winter and spring of 1956–57, and a parasite population suitable for the desired experiment was eventually found at Famoso in Kern County.

On June 4, 1957, sprays were applied by ground equipment on alfalfa at Famoso. The alfalfa was about 15 inches tall. Plots were 60 feet wide and 150 feet long and four replications were made. The plots were sampled with a sweep net for predators as well as parasites 5, 24, and 72 hours after application. The data are summarized in table 13.

Parathion and malathion applied at 3.0 and 9.7 ounces per acre, respectively, were extremely toxic to the adults of *Praon palitans*. Five hours after application, approximately 97 per cent of the adults were eliminated in the plots treated by these two materials. Phosdrin and Trithion applied at normal commercial dosages for control of the aphid were slightly less toxic, eliminating about 90 per cent of the adult parasites 5 hours after treatment. Systox applied at 1 and 2 ounces per acre gave 80 and 66 per cent reduction of the parasite population respectively. Even though Systox eliminated many of the adult parasites, the reduction was far less drastic than with any of the other materials tested. The greater reduction where the lower dosage of Systox was applied again probably indicates that at these low dosages there may not be a measurable amount of differential in toxicity to the parasite under field conditions. As was mentioned earlier, this same difference occurred in certain other of the tests involving predators.

One day after application, the adult aphid parasites were still at relatively low levels in the plots treated with parathion and malathion. There were numerous cocooned parasites in this field during the test. The two materials just mentioned have residual toxicity and apparently killed the tiny parasitic wasps as they emerged from their cocoons or as they migrated into the small plots from the large untreated area adjoining the experiment. Three days after application, there was little difference in numbers of adult parasites in the various treatments. Parasites were more abundant in the untreated plots than in the treated plots and more abundant than before treatment. This may reflect emigration of the adults from the treated areas where the aphid had been eliminated, into the untreated plots where aphids were still plentiful.

Mummified aphids containing cocoons of *Praon palitans* were collected 24 hours after treatment and brought into the laboratory to determine whether any of the insecticides had had a toxic effect on the parasite. It was found that none of the sprays affected the parasite in the cocoon stage.

In this experiment, parathion and malathion were also very toxic to the other beneficial insects. Coccinellid adults were greatly reduced 5 hours after application, and there was not a single lady-beetle larva collected in these two treatments at any time during the sampling period. *Orius* sp. was also greatly reduced. *Nabis* sp. was drastically affected by parathion but malathion was not nearly so toxic to this predator. *Collops* sp. were moderately reduced in the plots treated with parathion and malathion, whereas there appeared to be no toxic effect to *Collops* sp. from the other materials applied.

Five hours after application, lady-beetle adults and larvae were very scarce in the Phosdrin plots. This material also caused considerable mortality to *Orius* and *Nabis*.

Where Trithion and the two dosages of Systox (1 and 2 ounces per acre) were applied there was a slight reduction in lady-beetle adults 5 hours after treatment but a sharp reduction in the larvae. The apparently heavy larval mortality caused by Systox in this experiment is somewhat puzzling. In all other tests, Systox caused only a slight reduction in the larval population.

T

RELATIVE TOXICITY OF SEVERAL INSECTICIDE SPRAYS APPLIED
AND VARIOUS PREDATORS IN ALFALFA N

Numbers of insects per 150 sw

Treatment and dosage per acre	Coccinellids			*Praon palitans*			*Orius* sp.		
	1 day	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 d
	A* L	A L	A L	A	A	A	A N	A N	A
Parathion, 4.0 oz.	5—2	35—0	189—0	1	1	39	14—5	54—8	149-
Phosdrin, 1.5 oz.	19—132	127—56	300—100	2	12	50	78—15	139—108	432-
Systox, 2.0 oz.	60—312	217—662	583—196	1	12	114	287—26	273—217	438-
Untreated	106—385	113—1094	330—1919	2	26	125	413—22	465—131	306-

* A = adult; L = larva; N = nymph.

As for the decrease in the adult coccinellid population 24 hours after treatment, this may be correlated with the nearly complete elimination of the aphid population and the possibility that the adult lady beetles migrated to the outside of the testing area where aphids were still plentiful. Even though Systox caused a reduction in adult and larval coccinellids, its effect was not nearly as drastic as were the effects of parathion, malathion, and Phosdrin. Trithion was quite toxic to *Orius* sp. and *Nabis* sp.

Test No. 8. Except for the single test at Thermal involving two dosages of Systox, all materials had been applied by ground equipment on small plots. It was felt that at least one more experiment should be undertaken in which materials would be applied to large blocks of alfalfa by aircraft. A suitable alfalfa field was found near Famoso, Kern County, California, and sprays were applied on August 13, 1957. The alfalfa was nearing maturity and was about 25 to 30 inches tall. Plots were 215 feet wide and 1,240 feet long and were replicated three times. The toxicants were applied in 8 gallons of water per acre. In this experiment, the relative toxicities of parathion, Phosdrin, and Systox were tested on beneficial insects and on the spotted alfalfa aphid. Effects of those spray materials on beneficial insects were evaluated 1, 3, and 7 days after application by sampling with a sweep net. The data are summarized in table 14.

Parathion was again the most toxic material to all predators and to the aphid parasite *Praon palitans*. One day after application, this compound had essentially eliminated the adult and larval coccinellids. Approximately 95 per cent of *Nabis* sp., 96 per cent of *Orius* sp., and 100 per cent of *Chrysopa* sp. were eliminated in the plots treated with parathion.

At the time of application, coccinellid egg masses, larvae, pupae and adults were present in the experimental area, and during the test there was a population change from one life stage to another. At any period, however, only the larvae and adults could be sampled with the sweep net. Where parathion was applied, the coccinellid adults and larvae were essentially eliminated. The parathion residue continued its toxic action as the eggs hatched and as adults emerged from the pupae. Toxicity to the newly hatched larvae was particularly heavy, for at no time after application were there

PLANE TO THE SPOTTED ALFALFA APHID PARASITE *Praon palitans*
ERSFIELD, CALIFORNIA, AUGUST 13, 1957
ntervals after treatment

Nabis sp.			*Chrysopa* sp.			*Geocorus* sp.			*Collops* sp.		
y	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 days	1 day	3 days	7 days
N	A N	A N	A L	A L	A L	A N	A N	A N	A	A	A
9	11—13	30—4	0—0	3—13	24—25	14—4	7—15	5—2	12	29	38
35	63—180	199—85	1—5	20—60	37—96	35—11	38—29	141—41	13	37	63
93	275—576	381—322	9—9	39—46	55—42	15—11	57—60	91—19	24	39	58
41	247—311	277—178	38—5	54—26	74—40	19—2	22—10	23—6	18	48	33

any numbers of coccinellid larvae in the parathion plots. The adult population did increase to some extent after the first sampling date. These adults may have emerged from pupae after treatment or they may have migrated into the parathion plots. In either case, the toxicity of parathion to the lady beetles was extremely high.

Phosdrin was not quite so toxic to the lady beetles as parathion, but much more so than Systox. It appeared that the Phosdrin may have had some toxic effect on the coccinellid larvae beyond a 24-hour period.

Systox was the least toxic of the three materials. Adult coccinellids were reduced by approximately 43 per cent and the larvae by approximately 20 per cent 1 day after treatment. For an unknown reason, 3 days after treatment there were nearly twice as many adults in the Systox plots as in the untreated area. Many of the adults had recently emerged, as was attested by the softness of their bodies. Such adults were also found in the Phosdrin plots and to a much more limited extent in the parathion plots. The larval populations in the Systox and untreated plots increased rapidly 3 days after application. However, where Systox was applied, aphid mortality was 99.9 per cent 1 day after application, which essentially eliminated the food supply, while the aphid food supply in the untreated plots remained plentiful (table 15).

In the Systox plots, because of the limited food supply, the coccinellid larval population was far too high for all to survive. In observing the larvae 3 and 7 days after treatment, it was noticed that many were cannibalistic, which reduced their numbers. Many larvae were crawling on the ground in search of food while others undoubtedly died from starvation. Thus, on the seventh day after application, there was a tremendous difference in larval population between the Systox and untreated plots, where food was plentiful. In addition, many of the adults collected in the Systox plots 7 days after application were very small, indicating starvation. In the Phosdrin plots, there was some cannibalism and an occasional larvae was observed crawling on the ground but their numbers were not nearly so apparent as in the Systox plots. In the parathion plots, the coccinellid larval population did not recover during the testing period.

The data in table 14 indicate that the aphid parasites began to emerge from their cocoons soon after application. Those emerging in the plots treated with parathion were apparently adversely affected by the toxic residue. *Praon palitans* adults were less numerous in the Phosdrin plots than in the plots treated with Systox. However, since the peak of emergence occurred after application and Phosdrin has no residual action, no explanation can be offered for the lower numbers of *P. palitans* in the Phosdrin plots.

One day after application, there appeared to be little difference between *Geocorus* sp. numbers in any of the plots. However, the *Geocorus* sp. exhibit a certain activity cycle. Field observations indicate that many of them move up and down the plants at certain times of the day. It appeared that with this activity cycle the toxic residue of parathion gradually reduced their numbers.

Mummified aphids containing cocoons of *Praon palitans* were collected 24 hours after treatment and brought into the laboratory to determine

whether the sprays had had a toxic affect on cocooned parasites. It was found that none of the insecticides affected the parasite in the cocoon stage, a result that agreed with the data obtained in test no. 7.

During the experiment, large numbers of winged aphids invaded the test area. This presented an opportunity to study the advantages of a selective insecticide (Systox) which gave good initial kill of the aphid and allowed the enemies of the aphid to survive treatment. The data are summarized in table 15.

TABLE 15

POPULATION TRENDS OF SPOTTED ALFALFA APHID AFTER APPLICATION OF THREE INSECTICIDES BY AIRCRAFT WITH VARIABLE EFFECTS ON BENEFICIAL INSECTS IN THE EXPERIMENTAL PLOTS SUMMARIZED IN TABLE 14

Material	Toxicant per acre	Average number of apterous aphids per alfalfa stem at 3 intervals after treatment		
		1 day	7 days	10 days
Parathion	4.0 oz.	<1	11	14
Phosdrin	1.5 oz.	<1	8	8
Systox	2.0 oz.	<1	<1	1.5
Untreated	...	201	426	138

One day after application, there was an average of less than 1 aphid per alfalfa stem in all three treatments. The plots were next sampled 7 days after treatment. At this time, the insecticides had broken down and no longer killed the alate aphids flying into the treated plots or their young. Aphids averaged 11 per stem in the parathion plots, 8 per stem in the Phosdrin plots. Because of the drastic reduction of natural enemies, particularly where parathion was applied, invading aphids reproduced practically unhindered. By contrast, in the Systox plots where beneficial insects survived the treatment in goodly numbers, the aphids were destroyed as they reinvaded the plots and thus there was less than 1 aphid per stem. Ten days after application, aphids averaged 14 per stem in the parathion plots, 8 per stem in the Phosdrin plots, and only 1.5 per stem in the Systox plots.

SUMMARY AND CONCLUSIONS

When it was found that parathion and malathion, the first materials used for control of the spotted alfalfa aphid, were highly destructive to native predators of the aphid, a search was begun for a material or materials that would complement rather than suppress biological control. Early investigations showed that Systox was relatively nontoxic to native predators in comparison with parathion. In the same tests, pyrethrum, rotenone, and schradan also proved to be relatively nontoxic to beneficial insects; however, mainly because they failed to control the aphid, they were eliminated from further tests.

In order to compete economically with parathion and malathion, Systox

had to give effective aphid control at low dosages. Accordingly, experiments were conducted to test the effects of low dosages of Systox on *Therioaphis maculata.* It was found in these tests that Systox at 0.7 to 0.9 ounce per acre by ground equipment and 2 ounces per acre by aircraft gave satisfactory aphid control.

During the course of the investigations two promising experimental materials, Phosdrin and Trithion, were added to the list of potentially useful materials. Subsequently a number of experiments were conducted comparing the effects of commercial dosages of Systox, parathion, malathion, Phosdrin, and Trithion on native predators and the introduced aphid parasites.

When Systox was applied at dosages ranging from 0.7 to 6.2 ounces per acre it was not nearly so toxic to adult and larval coccinellids as parathion applied at 3.0 to 8.2 ounces per acre. Systox was also much less toxic to *Nabis* sp., syrphids, *Orius* sp., *Chrysopa* sp., and the small aphid parasites *Praon palitans* and *Trioxys utilis* than was parathion. Malathion applied at 9.1 to 9.7 ounces per acre by ground equipment was equally as toxic to the introduced aphid parasites and native predators (except *Nabis* sp.) as was parathion.

Phosdrin applied at 0.7 to 1.0 ounce per acre by ground equipment was not quite so toxic to the aphid parasites and native predators as parathion, malathion, or higher dosages of Trithion (11.6 ounces per acre), but was much more toxic than Systox. An additional advantage of Phosdrin over the more toxic materials was its short residual action. Thus, where this material was used, beneficial insects migrating into the treated area or emerging from the egg or pupal stages soon after application were unharmed.

Trithion was applied at dosages ranging from 5.0 to 11.5 ounces per acre. It was not nearly so toxic as parathion or malathion when applied at 5.0 ounces per acre. However, at 11.5 ounces per acre it was quite toxic to the native predators.

As mentioned above, where parathion and malathion are used on alfalfa they are highly toxic to a wide variety of phytophagous and entomophagous insects. In the case of the spotted alfalfa aphid control program, reëstablishment of the phytophagous species in the treated areas is greatly favored over that of its natural enemies. This, as mentioned previously, leads to repetitious treatments and increases the frequency of aphids resistant to organophosphorus insecticides. In addition, it is felt that the frequent and widespread use of parathion and malathion might cause resistance to develop in a wide variety of other insect pests frequently found in alfalfa fields, which, though not necessarily damaging to alfalfa, might carry resistance problems to other crops. It is extremely important that the entomologist be aware of this possibility wherever he uses insecticides of indiscriminate toxicity, especially where he is concerned with pest species which require widespread control and have the ability to reach the economic threshold rapidly.

One way to minimize this danger is through the use of selective insecticides which destroy the pest species but to a greater or lesser degree preserve the entomophagous forms. In the current investigations Systox proved to be just such a material and its use on a commercial basis has already alleviated the spotted alfalfa aphid problem in many areas.

Perhaps of even greater significance than the development of a "selective" control for *Therioaphis maculata* was the disclosure that where the selective material was used, insecticide-induced mortality of essentially 100 per cent was not necessary to give satisfactory control of the aphid. Thus in one experiment involving an aphid population resistant to all the tested materials, where Systox was applied and gave poor initial kill, the enemies of the aphid, which survived the treatment in goodly numbers, continued their attack on the resistant aphids and eventually effected complete control of the infestation. On the other hand, in this same experiment, where parathion and malathion were applied and the enemies of the aphid eliminated, the infestation actually increased soon after treatment since the surviving resistant adults reproduced unhindered by predation.

The investigations also showed that control with the selective material could be prolonged over that of the indiscriminate material even though initial kills by both materials were at a very high level. This occurred in one experiment where initial control of the aphid with both Systox and parathion was highly satisfactory. However, during the testing period large numbers of alate aphids invaded the treated area. Because coccinellids and other predators had been eliminated from the parathion-treated area these alate aphids reproduced unchecked after the parathion broke down, and the infestation level rose very rapidly. On the other hand, in the plots treated with Systox the aphid enemies survived in great numbers and maintained the invading aphid population at very low numbers even after the Systox was no longer effective.

The desirability of attaining a pest-control program in which chemical and biological control are as well integrated as possible is indisputable. This does not mean, however, that Systox would be the most desirable insecticide for use on other susceptible pests attacking other crops. Each pest problem and each crop has its own peculiar biological and ecological characteristics, and these must be analyzed and understood before any integrated chemical and biological control program can be undertaken. Through such ecological investigations on insect control we can expect chemical and biological controls to be utilized in true perspective.

LITERATURE CITED

Ahmed, Mostafa Kamal, L. D. Newsom, R. B. Emerson, and J. S. Roussel

1954. The effect of Systox on some common predators of the cotton aphid. Jour. Econ. Ent. 47(3):445–9.

Bieberdorf, G. A., and D. E. Bryan

1956. Research on the spotted alfalfa aphid. Oklahoma Agr. Expt. Sta. Bul. B-469. 12 pp.

Reynolds, H. T., and L. D. Anderson

1955. Control of the spotted alfalfa aphid on alfalfa in southern California. Jour. Econ. Ent. 48(6):671–75.

Stern, V. M., and H. T. Reynolds

1957. Developments in chemical control of the spotted alfalfa aphid in California, 1955–56. Jour. Econ. Ent. 50(6):814–21.

1958. Resistance of the spotted alfalfa aphid to certain organophosphorus insecticides in southern California. Jour. Econ. Ent. 51(3):312–16.

van den Bosch, R.
1956. Parasites of alfalfa aphid. California Agr. **10**(10):7, 15.

van den Bosch, R., H. T. Reynolds, and E. J. Dietrick
1956. Toxicity of widely used insecticides to beneficial insects in California cotton and alfalfa fields. Jour. Econ. Ent. **49**(3):359–63.

van den Bosch, R., E. I. Schlinger, and E. J. Dietrick
1957. Imported parasites established. California Agr. **11**(7):11–12.

IMPACT OF COMMERCIAL INSECTICIDE TREATMENTS[1]

RAY F. SMITH and KENNETH S. HAGEN

ECOLOGICAL STUDIES of the spotted alfalfa aphid, *Therioaphis maculata* (Buckton), in northern California during 1955, 1956, and 1957 have revealed that native predators play significant roles in governing the density of this aphid (Dickson, Laird, and Pesho, 1955; Stern, van den Bosch, and Born, 1958; van den Bosch *et al.*, 1959*b*; Smith and Hagen, 1956; Hagen and Smith, 1958). Throughout California these predators, along with entomophorous fungi, imported parasites, and physical factors of the environment, retain the spotted-alfalfa-aphid populations below the economic threshold during most of the alfalfa-growing season. At certain times of the year, the physical factors are the most important; at other times or within the same period at different localities any one of the biotic agents may be the most significant controlling factor; on other occasions, any or all combinations may be involved. Sometimes, or in certain alfalfa fields, the environmental conditions may be such that none of the regulating factors operate efficiently, and the aphid population rapidly increases to economic levels.

This study of the effect of insecticidal treatments on the native predators was started in the early spring, 1956, and was restricted to the central and northern parts of California. In 1956 and 1957 the introduced aphid parasites *Praon palitans* Muesebeck and *Trioxys utilis* Muesebeck had not yet become established over the entire area covered by this study (van den Bosch, 1956, 1957; van den Bosch *et al.*, 1959*a*). Thus even though the population fluctuations of the aphid and its natural predators were followed throughout the two years (1956–1957) in 40 commercial alfalfa-hay fields, in only 3 of these fields did the introduced hymenopterous parasites reach significant abundance during the study period. This paper is therefore essentially a report of the effects of insecticidal treatments on natural predators in a selected group of the 40 fields. A more detailed analysis of natural control in each of the 40 fields is in preparation.

INSECTICIDE APPLICATIONS AND POPULATION COUNTS

The study areas, which were scattered over the central portion of California, were established to obtain ecological data under the variety of climatic conditions which prevail there. Each study area was approximately 3 acres and located in a commercial alfalfa-hay field operated under normal cultural practices. All decisions concerning irrigation, fertilization, harvesting, and insect-control procedures were made by the farmer without special reference to any requirements of the investigation. Thus these study areas were not controlled experimental plots.

The aphid population trends were followed by the canister-count method first developed by Gray and Schuh (1941) for pea aphid, *Macrosiphum pisi* (Kaltenbach), on peas. In each study area on each sampling day, 4 to 8

[1] Received for publication August 13, 1958.

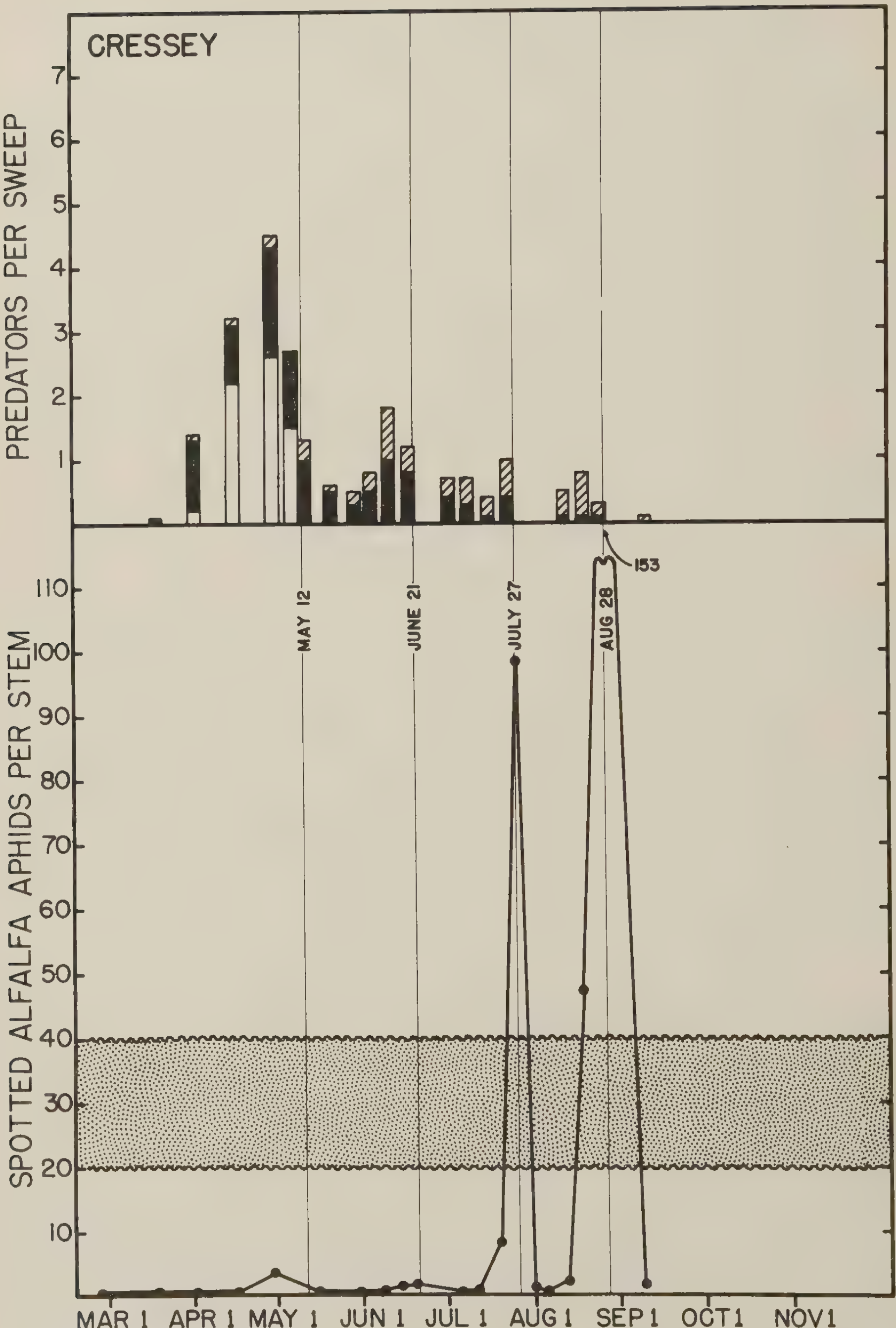


Fig. 1. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Cressey, Merced County, 1956. The dated vertical guide lines indicate cutting times. Stippled area represents the economic threshold for spotted alfalfa aphid. Predators include coccinellid adults (solid bar), coccinellid larvae (open bar), and other potential aphid predators (cross-hatched bar).

samples of 25 stems each were collected. The aphids were shaken from the stems in the canisters and brought into the laboratory for counting. Although all species of aphids were counted, only the data for *Therioaphis maculata* are presented here.

The predator populations were followed by the sweep-net method. In each study area on each sampling day ten ten-sweep samples were taken. All predators were identified and tallied in the field as they came from the net.

The chemicals used and the time of application were decisions of the grower and were, with one exception, applied in a normal commercial manner either by the farmer or by commercial operators. The exception was the Selma field: here, in addition to the grower's commercial practice, a special schedule of treatments was carried out by the local farm advisor.

APHID AND PREDATOR POPULATIONS

For the graphs in this paper, predators are grouped into three categories, the first two of which are coccinellid adults and larvae respectively. *Hippodamia convergens* Guérin and *H. quinquesignata punctulata* LeConte were the dominant species. *H. sinuata sinuata* Mulsant, *H. parenthesis* (Say), *Coccinella novemnotata franciscana* Casey, and, occasionally, other species, were important in some areas. The third predator category comprises a complex of species including larvae of *Chrysopa plorabunda* Fitch, adults and nymphs of *Nabis ferus* (Linnaeus), *Geocoris pallens* Stål, *G. punctipes* (Say), *G. atricolor* Montandon, and larvae of aphidophagous syrphids. Other predators and insects were recorded but are not reported here.

In interpreting the aphid population trends, it must be remembered that occasionally the time intervals between samples were not short enough to reflect completely the rapid population changes. In general, insecticidal treatments or the harvesting of the alfalfa hay immediately reduced the aphid populations to low levels. Where such effects would create confusion in the interpretation of the graphs, the connecting lines are omitted and the inferred direction of the population change is indicated by an arrow.

With No Insecticidal Treatments

Cressey. The usual pattern of relation between the spotted alfalfa aphid and its coccinellid predators in the San Joaquin Valley is shown by the situation in a field near Cressey, Merced County, in 1956 (fig. 1). During the first cutting period, a brood of coccinellid larvae developed on a moderate population of pea aphids (not shown on the graph). These beetles, in combination with *Entomophthora* fungus disease, reduced the aphid populations to low levels at the end of the first cutting period (May 12). During the second cutting period the aphid populations were held at low levels by the newly emerging and immigrating adult Coccinellidae. At this time there were not sufficient aphids present for the coccinellids to reproduce significantly. In the absence of significant numbers of aphidophagous predators or other population depressants, the spotted-alfalfa-aphid populations rose rapidly during the latter half of the third cutting period. The maximum recorded population count during this period was 98 aphids per

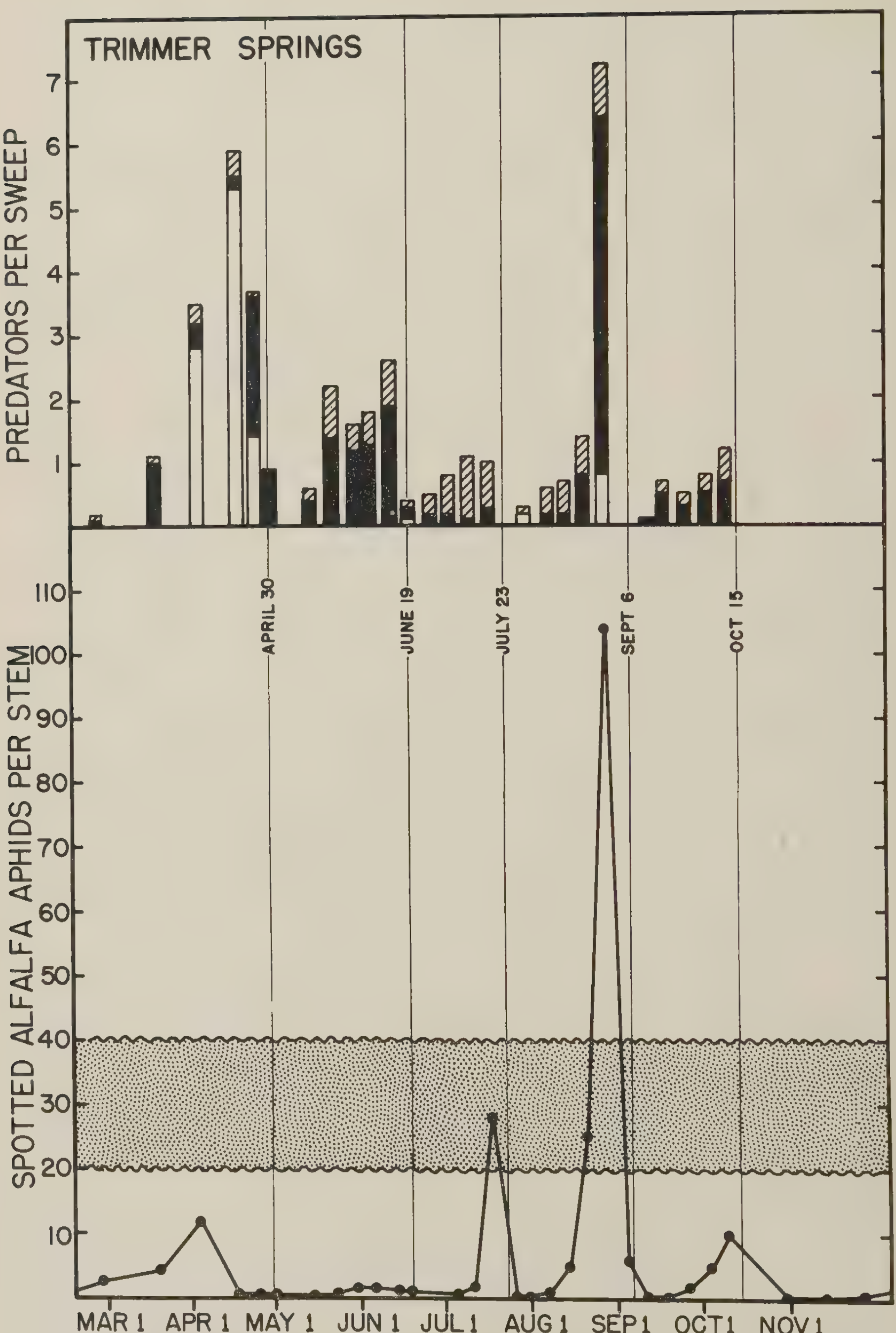


Fig. 2. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Centerville, Fresno County, 1956. Symbols as in fig. 1.

stem immediately before harvest (July 27). When the field was cut the aphid population dropped to a very low level.

Recovering from the effects of cutting, the spotted-alfalfa-aphid population in the Cressey study area again rose rapidly, in the absence of significant number of predators, to a level of 153 aphids per stem immediately before harvest of the fourth cutting. Again, after this cutting, the populations dropped to a low level.

Centerville. A very similar situation prevailed in the study area on Trimmer Springs Road near Centerville, Fresno County, in 1956 (fig. 2). During the latter half of March a flight of coccinellid adults entered this study area when the combined pea aphid and spotted-alfalfa-aphid populations were approximately 15 per stem. All coccinellid species reproduced and contributed significantly to the reduction in aphid abundance. During the second cutting period, the adult coccinellid population averaged over 1 per sweep and on June 6 the maximum combined aphid population was 1.5 aphids per stem. *Hippodamia convergens* and *H. quinquesignata punctulata* are not able to reproduce on this low population of aphids. On the other hand, *H. parenthesis* and *H. sinuata sinuata*, which together made up about one fourth of the coccinellids in this field, did reproduce to a limited extent. The larvae and adults of these two species, the few remaining adults of *H. quinquesignata punctulata* and large populations of *Nabis ferus* and *Geocoris*, which had developed on a high *Lygus* population, combined to hold the aphid populations at a low level until July 5. Following a reduction in their abundance after the harvest of the previous crop, the spotted-alfalfa-aphid population rapidly increased in the fourth cutting period on the new plant growth, when predators were nearly absent. A level of 104 aphids per stem was reached on August 29. The reduction in the aphid population in the latter part of this period was the result of a fungus epizoötic combined with predation by lady beetles and syrphid flies, which moved into the study area from other fields.

Effects of Cutting. In many instances the effect on the aphid population of cutting the alfalfa is comparable to a chemical treatment or heavy parasitism or predation. Immediately after the mowing, the cut hay dries, rapidly eliminating the abundant food source; only a scattered number of green leaves or new alfalfa shoots are available at the base of the plants for the aphids. Furthermore, soil surface temperatures in harvested alfalfa fields often exceed the upper limit for aphid survival. The aphids that are able to find leaves or shade at the base of the plants are concentrated in so small an area that predator efficiency is markedly increased. But it should be mentioned that aphid populations often reach damaging numbers many days prior to the normal cutting date. Therefore, only in special instances can a cutting be used as a means of economically controlling the populations.

With a Fixed Insecticidal Schedule: Selma

During the 1956 growing season, a study was conducted near Selma to determine the effects of grower treatments and an indiscriminate fixed spray schedule on native predators and yields of alfalfa.

In this experiment four plots were treated according to a fixed schedule.

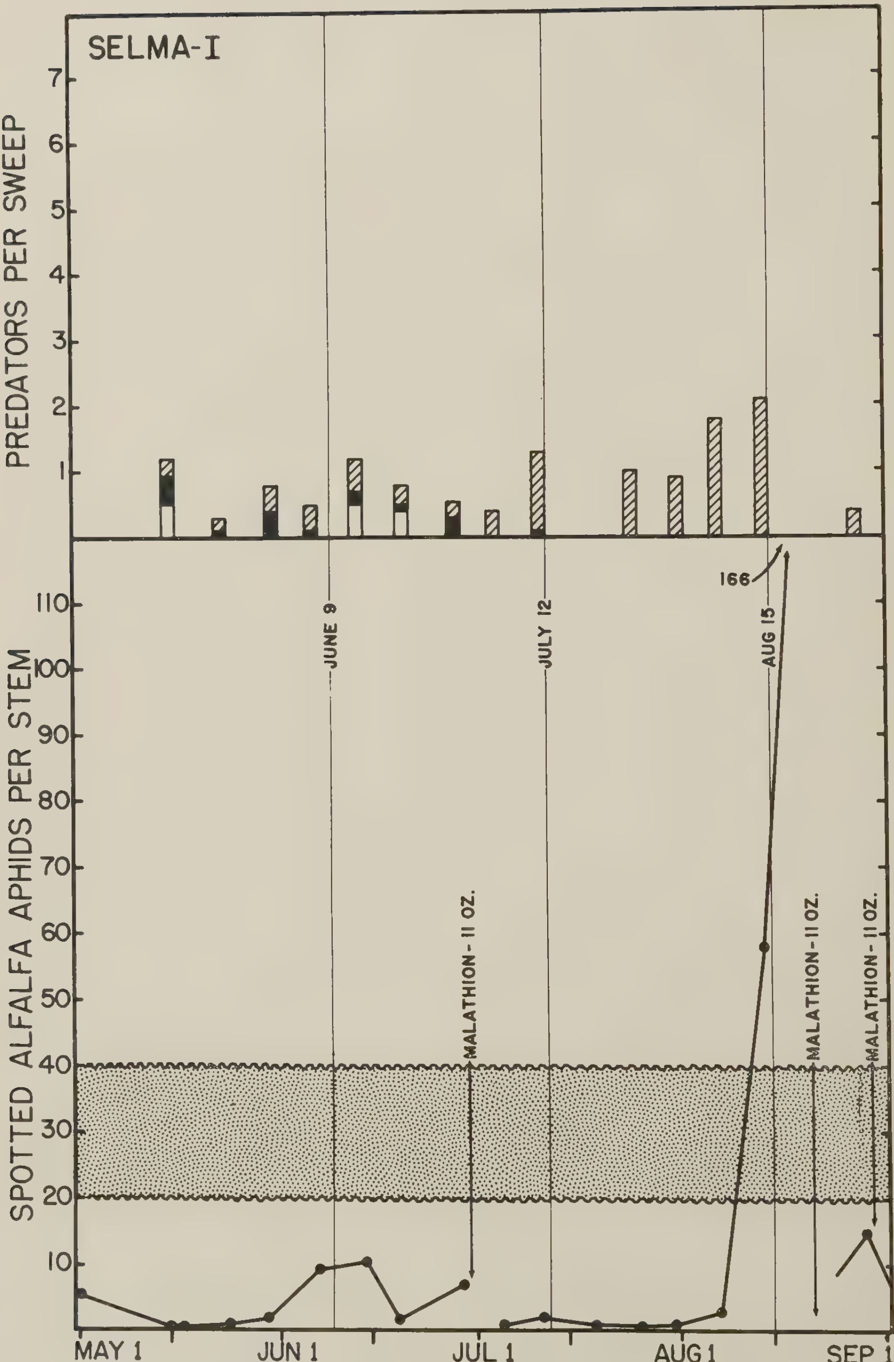


Fig. 3. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Selma, Fresno County, 1956. Insecticidal treatments applied by ground rig on basis of growers' evaluation of aphid hazard. Symbols as in fig. 1.

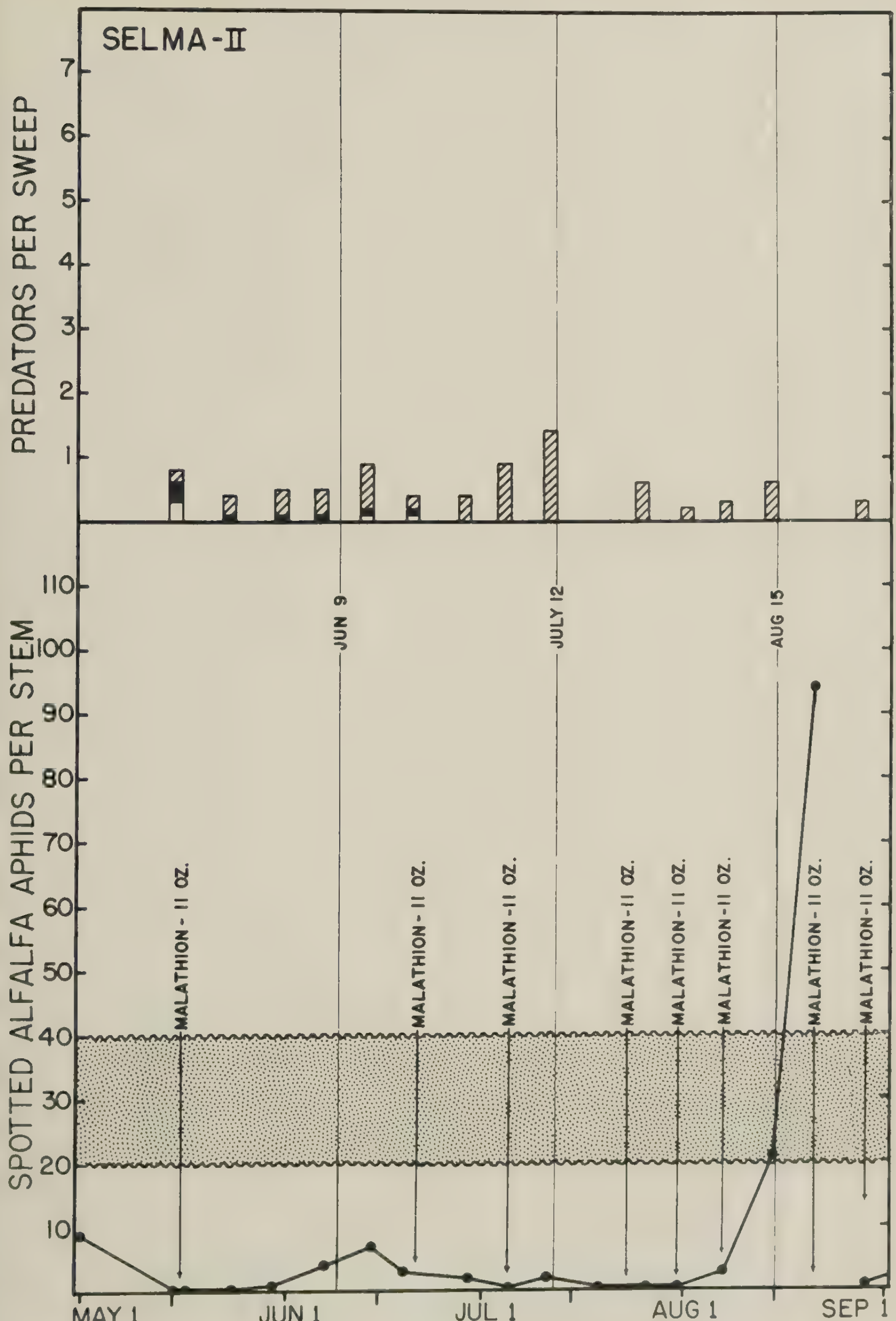


Fig. 4. Spotted-alfalfa aphid and predator population trends in an alfalfa field near Selma, Fresno County, 1956. Insecticidal treatments applied by ground rig on basis of a fixed schedule. Symbols as in fig. 1.

Table 1

RELATIVE NUMBERS OF COCCINELLIDAE IN GROWER-TREATMENT AREAS AND FIXED-TREATMENT AREAS; SELMA, 1956

Coccinellid species	Coccinellidae per hundred sweeps											
	Areas treated on June 21*						Areas not treated June 21†					
	June 13		June 20		June 28		June 13		June 20		June 28	
	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae	Adults	Larvae
Hippodamia convergens	5.0	0.6	5.6	2.5	0	0	4.6	12.7	0.4	11.3	20.8	0
Hippodamia quinquesignata	1.9	2.5	3.9	2.5	0	0	5.6	19.2	1.0	6.7	17.9	0
Hippodamia parenthesis	2.5	4.2	1.9	0.3	1.1	0	1.9	22.7	1.7	2.3	30.4	0.8
All Coccinellidae	9.7	7.6	11.7	5.3	1.1	0	12.5	57.5	3.3	20.5	69.5	0.8

* Three fixed-schedule plots.
† Four grower-treatment plots.

without regard to the existing insect populations; three other plots received the grower's normal treatment program, in which the first appearance of honeydew was the signal to treat. Each experimental plot was approximately 1.7 acres, and each treatment was applied by a ground sprayer at the rate of 11 ounces of actual malathion per acre.

Population trends, treatments, and the resultant effects of the sprays on aphid predators from a plot of each of the two types of schedule are shown in figures 3 and 4. The grower's program (see table 2) involved no treatments in the first two cutting periods, one (June 30) in the third period; two (July 31 and August 8, grower treatment A in table 2) in some parts of the field and none (grower treatment B, table 2) in other parts of the field in the fourth period; and three (August 21, 30, and September 19) in the fifth. The fixed schedule involved no treatment in the first cutting period, one in the second period (May 16), two in the third (June 21 and July 5), three in the fourth (July 23, July 31, and August 7), and three in the fifth (August 21, August 29, and September 12).

Populations during Second and Third Cutting Period. In the plots subjected to the fixed schedule, the lady-beetle population (approximately 0.4 adult and 0.3 larva per sweep) was eliminated by the first treatment on May 16 (fig. 4). In addition, this treatment appeared to affect the lady-beetle populations in plots not treated at this time (fig. 3), as there was some movement of the coccinellids from plot to plot within the field. In the treated plots, the lady-beetle population started to increase again by immigration (fig. 4) in the early part of the third cutting period, and apparently had begun to reduce the aphid infestation when another treatment was applied on June 21. No lady beetles were taken in this plot for the remainder of the growing season. The impact of the malathion treatment of June 21 on coccinellids is shown in table 1. This table is based on the data from the seven plots in the study area rather than the single plots represented in figures 3 and 4. Prior to the June 21 treatment there was a much higher lady-beetle population in the grower-treatment plots than in the fixed-schedule plots. This is a reflection of the May 16 application in the latter plots, which reduced both aphids and coccinellids (fig. 4). The combined pea-aphid and spotted-alfalfa-aphid population in the untreated plots averaged 0.6 aphid per stem on May 24, 2.1 on May 30, and 10.0 on June 7. This relatively low aphid population provided sufficient food for coccinellid reproduction. By contrast, fixed-schedule plots, which received the May 16 application, had 0.3 aphid per stem on May 24, 0.9 on May 30, and 4.0 on June 7, and little coccinellid reproduction. The low numbers of lady-beetle larvae present in the untreated plots on June 28 resulted largely from pupation.

The first insecticide application by the grower on June 30 eliminated the moderate population of lady beetles which had up to that time kept the spotted-alfalfa-aphid population at a low level (fig. 3). In July and August the only predators remaining in this area in significant numbers were *Nabis* and *Geocoris*, which had developed mainly on a population of *Lygus*.

Populations during Fourth Cutting Period. During the fourth cutting period, the aphid populations remained at low levels until the second week of August, when large numbers of alate spotted alfalfa aphids flew into

TABLE 2

YIELD PER ACRE AND TOTAL APHID-DAYS ON THE SECOND TO FIFTH CUTTINGS; SELMA, 1956

Treatment	Treatment dates	Yield, tons per acre, in cuttings II to V				Total aphid-days in cutting periods II to V			
		II	III	IV	V	II	III	IV	V
Grower treatment A	June 30, July 31, Aug. 8, 21, 30, Sept. 19	2.18	1.84	1.46	1.18	132	154	348	935
Grower treatment B	June 30, Aug. 21, 30, Sept. 19	2.31	1.93	1.71	1.20	102	200	197	562
Fixed schedule	May 16, June 21, July 5, 23, 31, Aug. 7, 21, 29, Sept. 12	2.19	1.68	1.56	1.17	82	72	84	352

the study area. The outside margins were infested first and in some plots aphid-infestation levels were as high as 134 aphids per stem on August 7. The two marginal plots were treated on August 8, for there were no predators to check further population increase. The plot represented in figure 3 was in the interior of the study area and received no treatments during the fourth cutting period. Due to the differential flight into the field, in this untreated plot the aphid population level did not reach its peak (57.7 aphids per stem) until August 14. In the plots receiving three treatments (fig. 4) in the fourth cutting period, the aphid population averaged 21.3 per stem on August 14.

Populations during Fifth Cutting Period. After the cutting of the fourth crop on August 15, the study area could not be treated again until the bales of alfalfa had been removed. During this period the aphid populations increased rapidly in the absence of predators. In the plots which were not treated in the fourth cutting period, the spotted-alfalfa-aphid infestation level rose as high as 166 aphids per stem. In these plots, the growth of the fifth crop was markedly delayed.

By the end of the fifth cutting period, heavy spider-mite infestations had developed in all plots receiving the fixed-schedule treatment. In some parts of these plots the mite infestations caused serious defoliation or heavy leaf damage on the lower halves of the plants. In other parts of the study area, mites, though present, did not occur in damaging numbers.

Insect Injury. The small difference in aphid populations as a result of the two types of treatments during the second and third cutting periods did not affect yields. This emphasizes the futility of "insurance" treatments not based on insect populations or of treatments applied according to a fixed schedule not based on aphid abundance. In the second cutting period, the cumulated aphid-days (one aphid-day equals one aphid per stem per day) were 117 in the plots with no treatment and 82 in the plots receiving the May 16 treatment. The yield was 2.24 tons per acre in the former and 2.19 in the latter. In the third period the cumulated aphid-days were 177 in the plots with no treatment and 72 in the plots receiving the June 21 and July 5 treatments. The yield was 1.88 tons per acre in the untreated plots and 1.68 tons per acre in the plots receiving two treatments of malathion in the third cutting period.

At the time of harvest, alfalfa in the plots treated once during the fourth cutting period on August 8 (grower treatment A, table 2) was slightly sticky with honeydew and there was slight sooty mold on the bottom 10 inches of growth. Alfalfa in the plots receiving no treatment during the fourth cutting (grower treatment B, table 2) had light honeydew on the lower leaves and some leaf injury from lepidopterous larvae [*Prodenia praefica* Grote and *Loxostege sticticalis* (Linnaeus)]. The fixed-schedule plots showed no spotted alfalfa-aphid honeydew or caterpillar injury, but light spider-mite damage was appearing in some plots. These pest levels were not correlated with yields (table 2) or protein content of the cured hay.

In summary, the aphid-population differences between plots receiving excessive treatments and those receiving the grower's treatment schedule were not of economic significance.

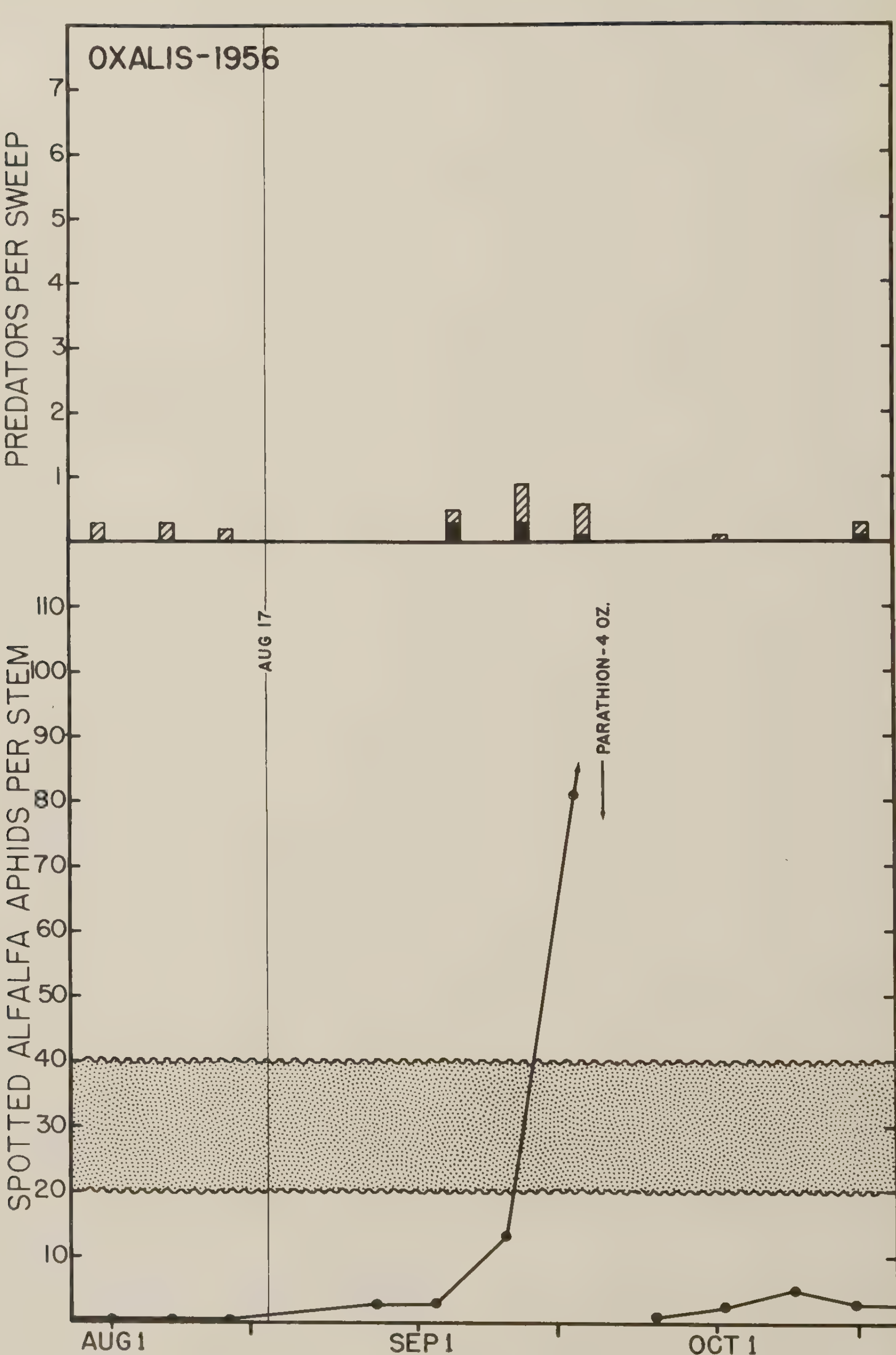


Fig. 5. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Oxalis, Fresno County, 1956. Symbols as in fig. 1.

With Nonselective Insecticides

Selma. As has been demonstrated in a companion paper (Stern and van den Bosch, 1959) when nonselective insecticides, such as malathion or parathion, are used to lower threatening aphid populations, most of the enemies of the aphids are also eliminated. The work of Stern and van den Bosch is supported by the evidence in the Selma study area, where the use of malathion eliminated practically all lady beetles from the field (table 1, figs. 3 and 4). The surviving predators were almost entirely *Geocoris* and *Nabis*. These predaceous bugs had developed on a heavy lygus-bug population and when the alfalfa growth was short they were significant in helping to keep the aphid population low. When a large number of aphids flew into the field about the second week of August, however, they were not able to prevent the increase of the aphids to economic levels. In spite of three malathion treatments in the fourth cutting period, the aphid population increased rapidly in mid-August.

Treatment with a nonselective insecticide does not necessarily provoke an immediate resurgence of the aphid population. If the insecticidal treatment has been thorough and adequate and the aphid population is nonresistant, resurgence may not occur until the population has had an opportunity to complete two or three generations. More often resurgence occurs when there is a heavy immigration of winged aphids into the field from neighboring fields. These adults, in the absence of biotic checks, can quickly increase the aphid population to economic levels.

Oxalis. Under certain environmental conditions, resurgence may not occur because the plant growth in such alfalfa fields is unsatisfactory for the aphids. The situation illustrated in figure 5 is an example of such a field. During late July, 1956, the populations of *Therioaphis* in this field had been reduced to low levels by hot, dry conditions. Irrigation had been delayed and on 8 out of 15 days from July 11 to July 25 the maximum air temperature was 95°F or higher. The alfalfa was cut early on August 17 to reduce a threatening infestation of lepidopterous larvae (*Colias philodice eurytheme* Boisduval and *Prodenia praefica*). The first irrigation of the fifth cutting period was delayed until September 3. With the renewal of growth following irrigation, and the arrival of a moderate flight of aphids into the field the aphid population started to increase. A treatment for *Colias* and *Therioaphis* with 4 ounces of parathion per acre on September 20 eliminated the moderate population of predators which had started to develop. The aphid population did not rebound because of the lack of a significant flight into the field and the unfavorable plant conditions. In late September and early October the plants were woody and overmature, with most of the lower leaves gone. The length of this cutting period was 62 days.

The following year, in this same field, two malathion treatments were applied during July and August (fig. 6). During the third cutting period the spotted-alfalfa-aphid population rose to a level of 80 per stem on July 3. During the previous 2 weeks a population of approximately one coccinellid adult per sweep had been present. This population of beetles was not large enough to cope with a flight of approximately 0.8 alate per stem into

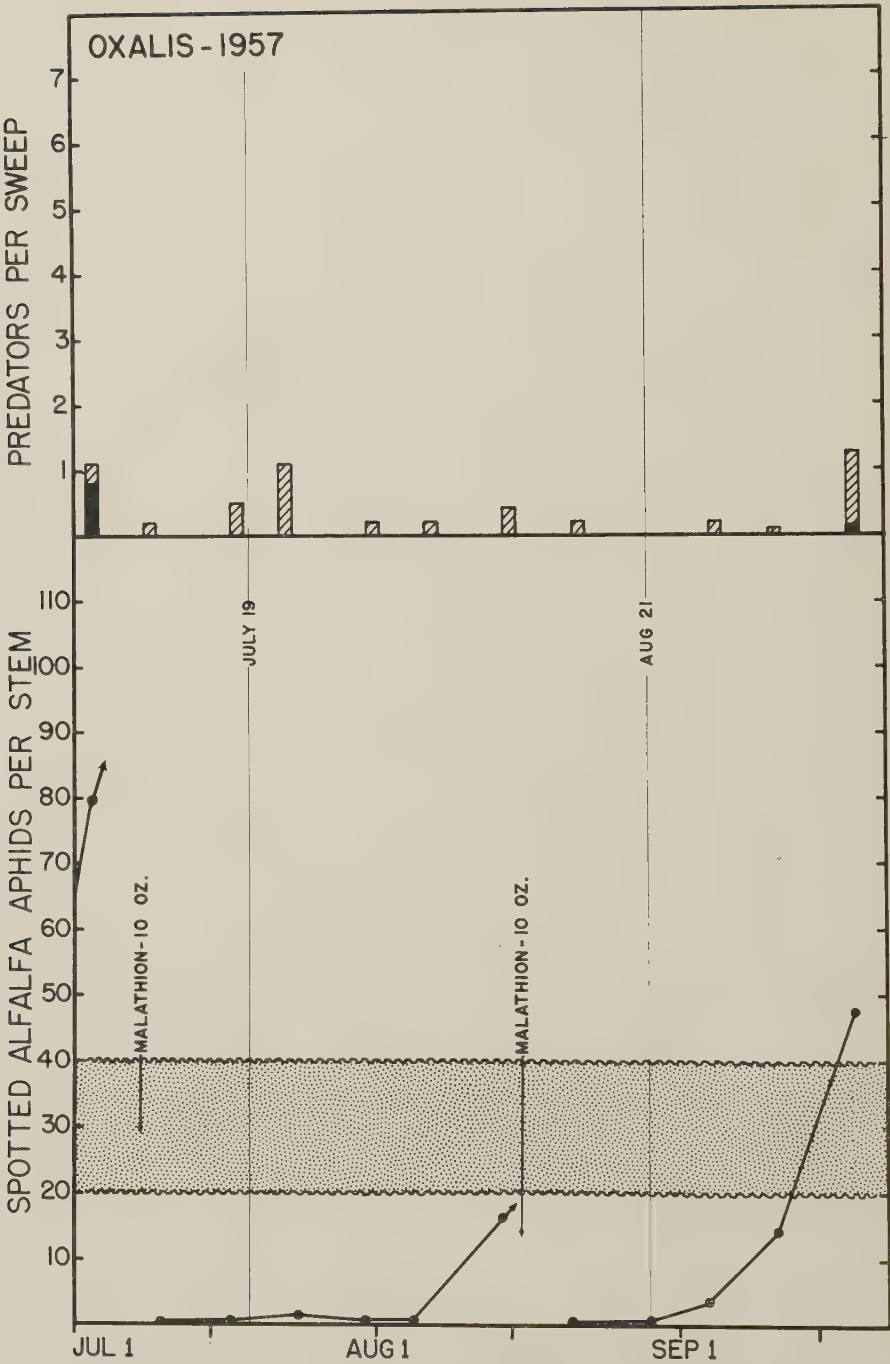


Fig. 6. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Oxalis, Fresno County, 1957, before and after treatments with a nonselective insecticide (malathion). Symbols as in fig. 1.

the field. The coccinellids were able to reproduce and on July 4, 97 per cent of the females were gravid. A treatment with malathion on July 8, eliminated all of these coccinellid adults and any larvae which hatched later.

In the following cutting period, the field was not irrigated until July 31. New growth followed this irrigation, after which a flight of alate aphids averaging about 1 per stem moved into the field and in the presence of very few predators rapidly produced an economic infestation; thus, another treatment was necessary in mid-August. In September the aphid population again rose rapidly.

Additional effects of nonselective treatments are shown in figure 12.

With Selective Insecticides

Patterson. Up to August 5, 1957, the spotted-alfalfa-aphid population had remained low in the Patterson field (fig. 7). The maximum count had been 15.5 spotted alfalfa aphids per stem on July 3. These low infestation levels largely resulted from the activity of coccinellids. During the third cutting period, in late July and early August, the coccinellid populations dropped to very low levels, ranging from 0 to 3 adults per 100 sweeps. In early August a large flight of alate *Therioaphis* moved into the field and, with predators nearly absent, the aphid population increased to high levels. However, as the time of harvest was near, the crop was mowed. The high aphid population that developed late in the third cutting period and on the new growth of the fourth crop caused moderate damage and some stickiness from the honeydew. The population was eliminated by a treatment with 1 ounce of Systox per acre on August 20. This treatment did not seriously affect a small population of Coccinellidae which were present in the field after the August 12 cutting. This population of coccinellids reproduced and were able to keep the spotted-alfalfa-aphid population from causing economic damage during the entire fourth cutting period. In combination with the effects of the September 18 cutting and a moderate population of *Chrysopa* larvae (0.2 per sweep), these lady beetles reduced the aphid population to low levels and it remained low for the rest of the year.

Hanford. In a Hanford field during the growth of the crop which was harvested on July 20, 1957, the spotted-alfalfa-aphid population reached a high level of 291 aphids per stem in the study area. A population of *Hippodamia convergens* and *H. quinquesignata punctulata* of approximately 1.8 larvae per sweep reduced this high population of aphids to 14 per stem on July 24 and to 1.6 per stem on July 30 (fig. 8). After the pupation of the very even brood of coccinellid larvae and a moderate flight of alate spotted alfalfa aphids into the area, the aphid population again began to increase. On the basis of higher populations in other portions of the field, the grower treated the entire field with 2 ounces of Systox per acre. This selective treatment did not upset the natural control in the study area, and the aphid population was held low for the remainder of the year by a combination of predators and the aphidiine parasite, *Praon palitans* Muesebeck. On September 18, the estimated parasitization was 43

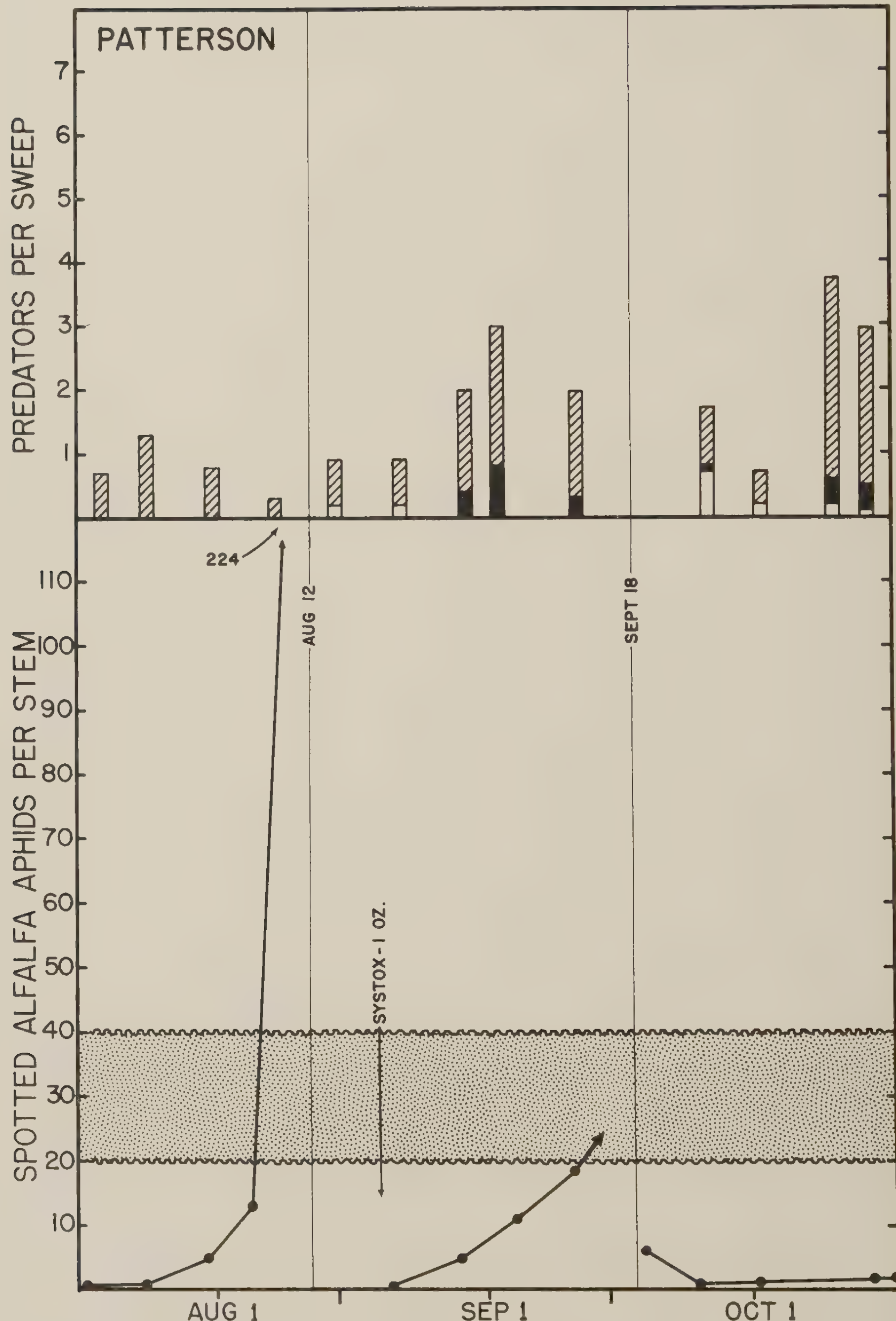


Fig. 7. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Patterson, Stanislaus County, 1957. Insecticidal treatment applied by air by commercial pest-control operator. Symbols as in fig. 1.

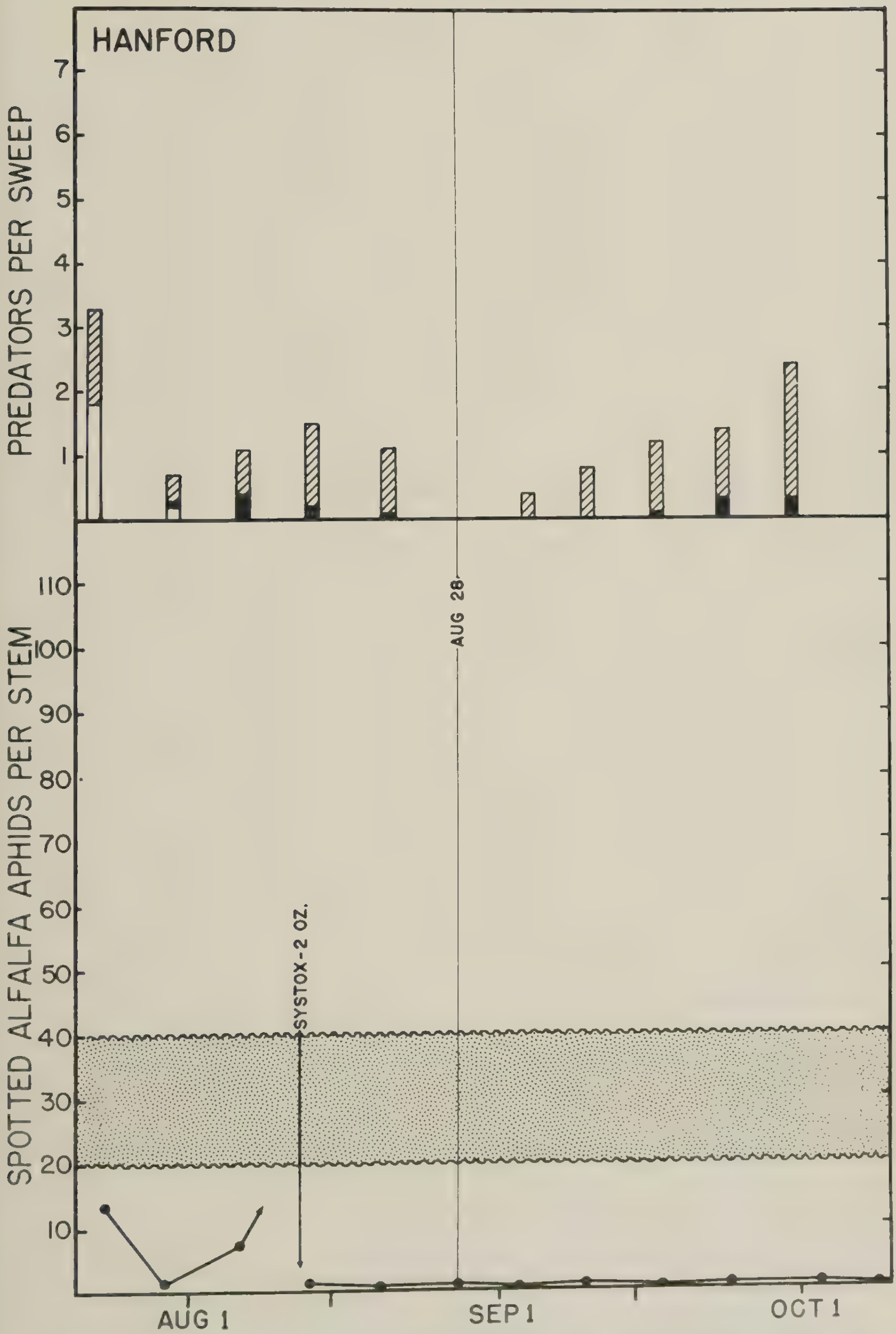


Fig. 8. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Hanford, Kings County, 1957. Insecticidal treatment applied by air by commercial pest control operator. Symbols as in fig. 1.

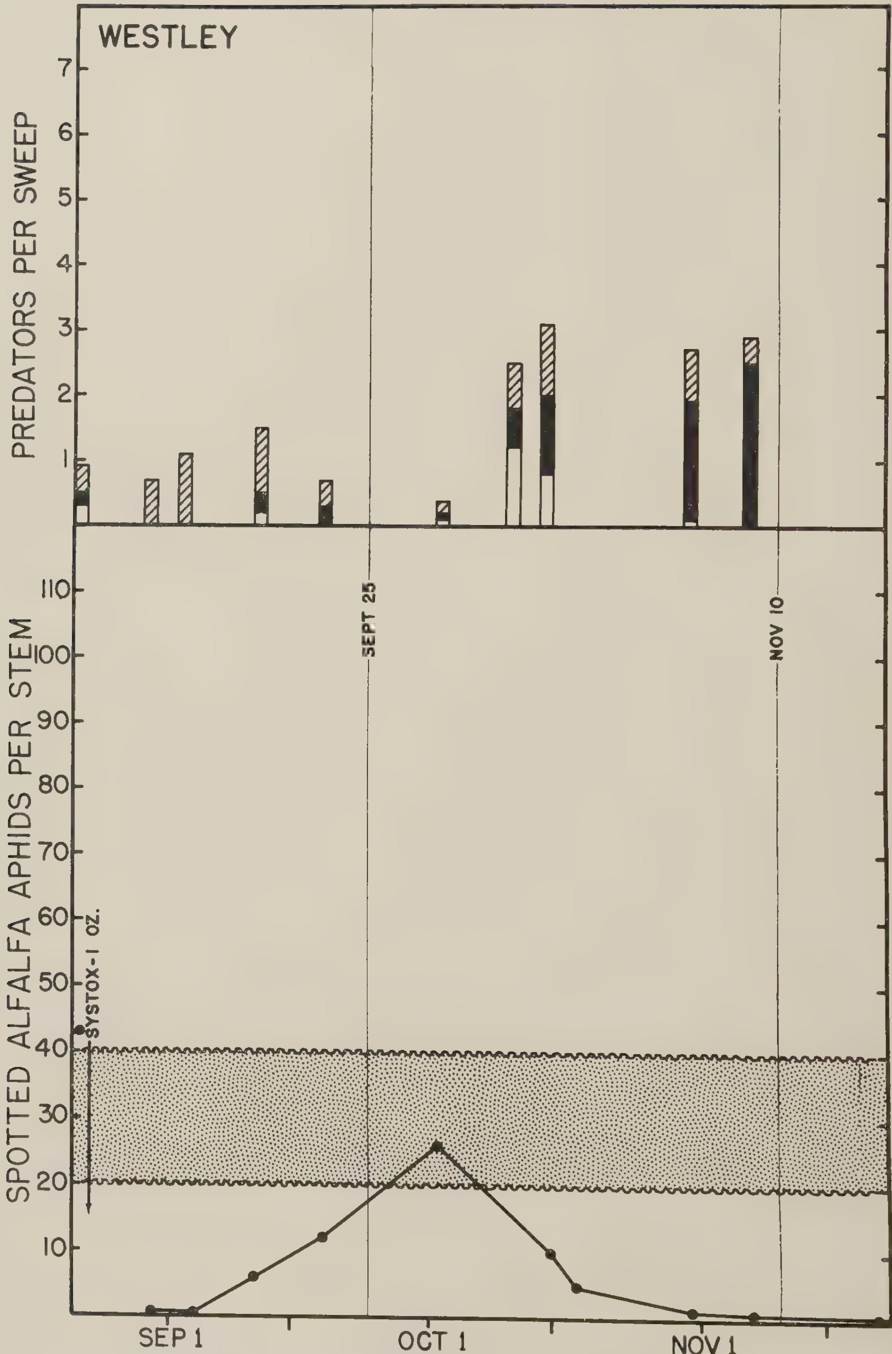


Fig. 9. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Westley, Stanislaus County, 1957. Insecticidal treatment applied by air by commercial pest-control operator. Symbols as in fig. 1.

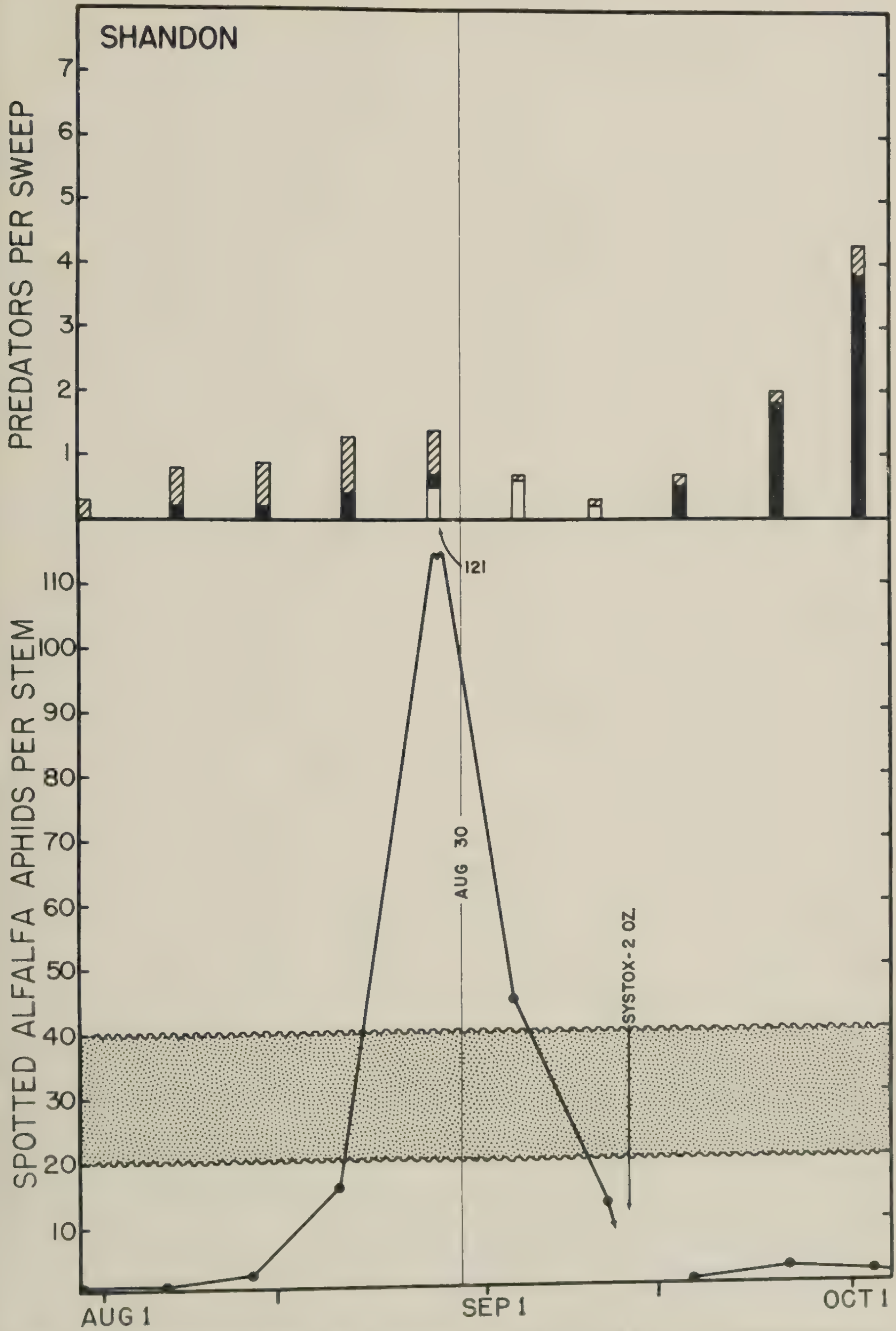


Fig. 10. Spotted alfalfa aphid and predator population trends in an alfalfa field near Shandon, San Luis Obispo County, 1957. Delayed insecticidal treatment applied by air by commercial pest-control operator. Symbols as in fig. 1.

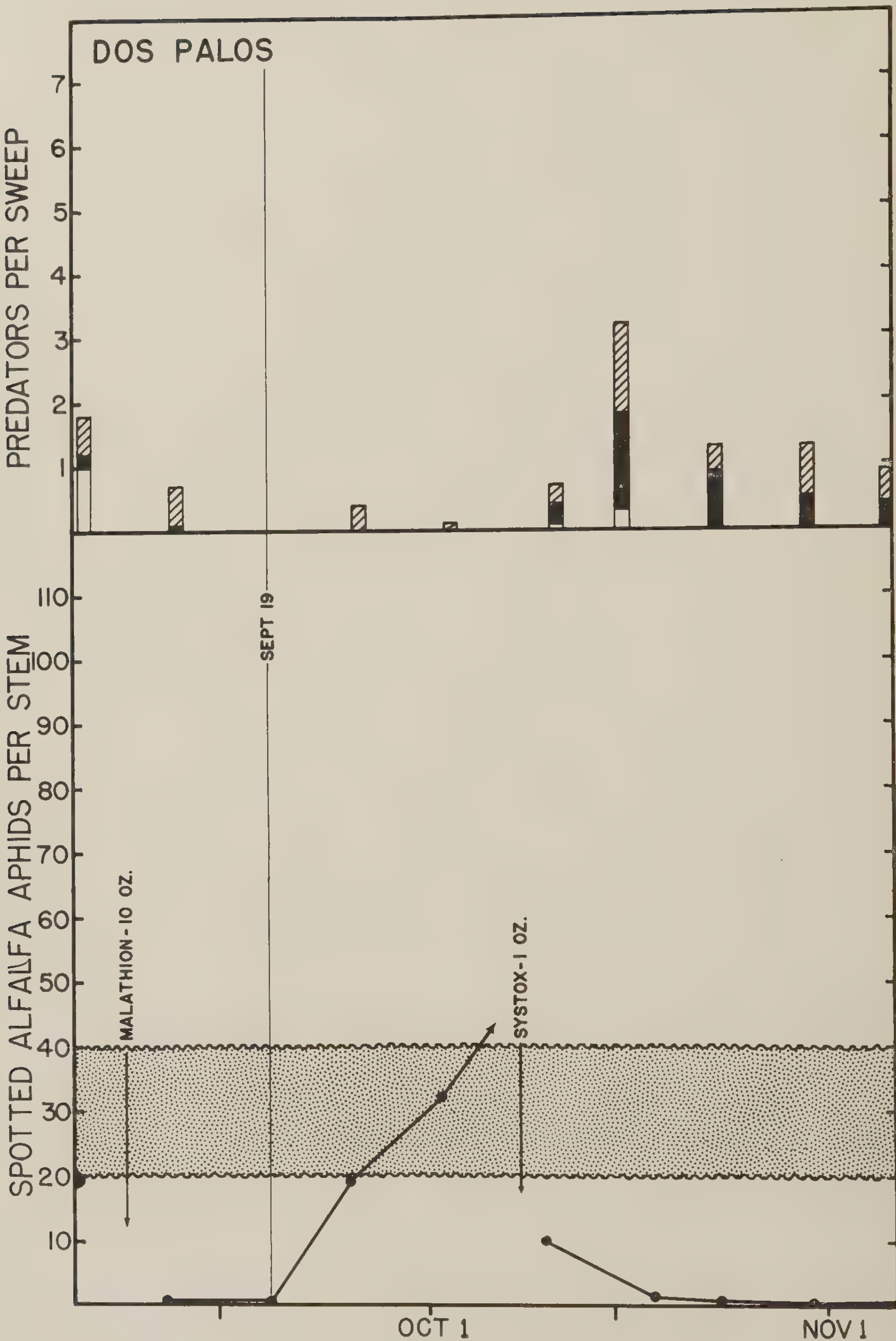


Fig. 11. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Dos Palos, Merced County, 1957. Insecticidal treatment applied by grower's ground sprayer. Symbols as in fig. 1.

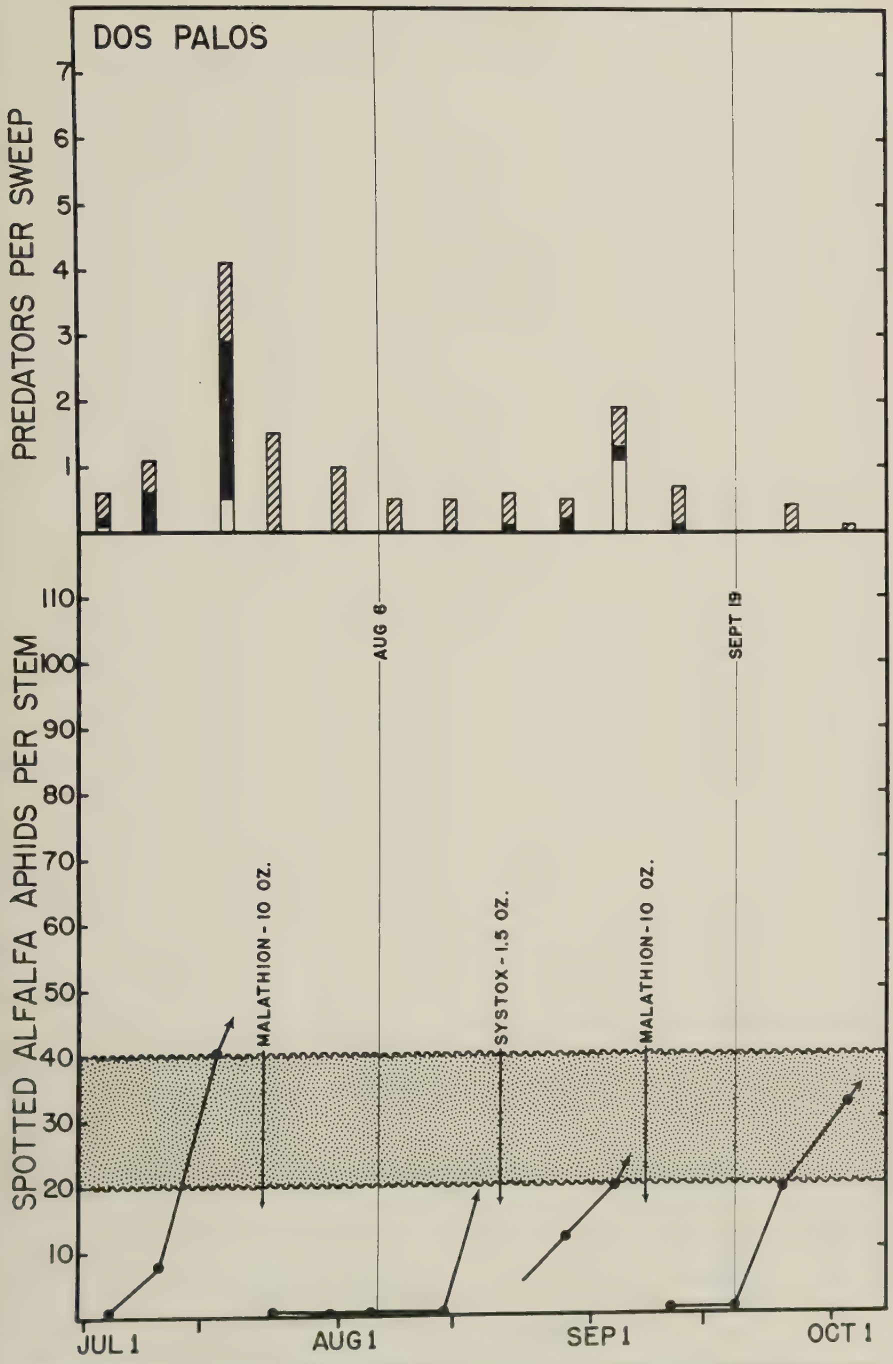


Fig. 12. Spotted-alfalfa-aphid and predator population trends in an alfalfa field near Dos Palos, Merced County, 1957. Symbols as in fig. 1.

per cent. On the same date the predators were represented by 6 lady-beetle adults, 112 *Nabis ferus,* and 2 *Geocoris* per 100 sweeps.

Westley. In mid-August, 1957, a large number of alate spotted alfalfa aphids moved into a Westley field. The moderate predator population responded to this invasion but was not able to cope with the rapid rate of increase of the aphid. A selective treatment with 1 ounce of Systox per acre on August 27 reduced the population of 42 aphids per stem to low levels (fig. 9). The number of predators sampled in the study area declined temporarily because of the low number of aphids and pupation of larvae. The predators increased slightly during the remainder of the cutting period. General observation in the field indicated that *Chrysopa* larvae were especially important here, but this was not adequately shown by the sweep counts. Apparently these larvae were more abundant in the lower parts of the plants, which were not sampled by the sweeps. Although predators were not high in September they were able to slow the rate of increase of the aphids and to increase themselves so that by October they dominated the situation and prevented the *Therioaphis* population from causing serious economic damage.

Shandon. In mid-August, 1957, after movement of alates into the study area, the spotted-alfalfa-aphid population started to increase (fig. 10). The moderate lady-beetle population responded to this increase and on August 28 reached a level of 21 adults and 47 larvae per 100 sweeps. These coccinellids were not able to prevent the aphid increase to a level of 121 per stem at harvest time (August 30). However, combined with the effects of the mowing of the crop, the coccinellid larvae, with the searching area reduced to the alfalfa stubble, were able to bring about a rapid decline in the aphid population. Unfortunately the grower, not realizing that the aphids were being eliminated in the stubble, made an unnecessary insecticidal treatment. Systox at 2 ounces per acre was applied by air on September 13. It is of special significance that this treatment did not disrupt the natural enemies present. Lady-beetle populations present in the field after the treatment held the aphid population low for the remainder of the season.

Dos Palos. During the fifth cutting period (fig. 11) this field was treated on September 8 by air with 10 ounces of malathion. This treatment was applied to eliminate a population of 19.5 spotted alfalfa aphids per stem; but it also eliminated a coccinellid population of 0.2 adult and 1.1 larvae per sweep. The adult coccinellids shown in the September 12 count were newly emerged beetles which soon disappeared, probably because the aphids had been eliminated.

After the harvest on September 19, the spotted-alfalfa-aphid population rose rapidly to treatment levels. In contrast to the malathion treatment in the previous cutting period, the use of 1 ounce of Systox favored biological control. Soon after the treatment, lady beetles moved into the area from other fields and held the population at a low level for the remainder of the season.

The use of a selective insecticide will not be as spectacular in its effects on the aphid population as in the cases cited above if biotic agents are not present to continue the suppression of the pest population. The situation

in this field during July, August, and September, 1957 (fig. 12) illustrates this point. In this field on July 23, a nonselective treatment with malathion eliminated a coccinellid population of 2.4 adults and 0.5 larva per sweep. The other predators were largely *Nabis* and were not seriously affected. In mid-August the spotted-alfalfa-aphid population again rose rapidly, and on August 21 the field was treated with 1½ ounces of Systox per acre. A population of 0.1 lady-beetle adult per sweep was able to survive and reproduce after this treatment. However, the resultant brood of coccinellid larvae of about 1 per sweep was not able to cope with the large flight of alates which moved into the field on about September 1. The field was treated with malathion and again the coccinellids were eliminated. In the following cutting period the aphid population rose rapidly after the harvest of the crop. (Compare with figs. 7, 8, and 9).

CONCLUSIONS

In the Central Valley of California, native aphid predators are significant factors in holding populations of the spotted alfalfa aphid below economic levels for much of the growing season (figs. 1 and 2). In other alfalfa-growing areas they are capable of holding the aphid populations below economic levels throughout the year. The Coccinellidae, especially the genus *Hippodamia,* are the most important of these predators, although species of *Chrysopa, Nabis, Geocoris,* and larvae of certain syrphid species may be important at certain times in some fields.

Insecticidal treatments are necessary to keep the spotted-alfalfa-aphid populations below economic levels during the times of the year when biological control is inadequate. Such necessary insecticidal treatments should be designed to throw the balance back in favor of the biological control. Insecticides if used unwisely will eliminate the predators present in a field and thus will often produce a situation which requires repeated treatments. Treatment by schedule without reference to the insect populations (fig. 4) is particularly hazardous. Such treatment schedules bring on the development of resistant strains of insects and can cause increases in other pests. At the same time there is no evidence that such attempts to hold the spotted alfalfa aphid at very low population levels produce profitable increases in the yield or quality of hay.

Treatments with nonselective materials such as malathion and parathion eliminate or drastically inhibit the natural control, but this use does not always result in an immediate resurgence of the spotted-alfalfa-aphid populations. Where such treatments have been properly applied and the aphid populations reduced to low levels, the populations, in the absence of heavy flights of alates, recover slowly. If, on the other hand, there are heavy flights of alates into the field, the population will, in the absence of natural control, increase rapidly to high levels. In some instances where plant growth conditions are unsatisfactory, rapid resurgence will not occur under any circumstances.

Treatments with selective insecticides such as Systox will, in general, by preserving natural enemies, have the effect of throwing the balance

back in favor of the natural enemies. Such selective treatments should be applied whenever the aphid population reaches the economic threshold, regardless of the existing status of natural enemies in the fields. The use of a selective insecticide will not, however, insure any longer-lasting control of the aphids than a nonselective material if no natural enemies are present.

ACKNOWLEDGMENTS

The authors are indebted to the many who have assisted in making the numerous counts necessary in a study such as this. These include Sherbourne F. Cook, Jr., William E. Ferguson, Harry M. Graham, Charles Hogue, Ibrahim K. Kaddou, Herman Menke, John Nakata, John D. Paschke, Louis Ruud, Frank Skinner, Mel Sparks, and George P. Willsey. We also wish to acknowledge the assistance of F. E. Souther, John E. Swift, Dan Irving, Eugene Stevenson, Richard Eide, Curtis Berryman, and Chester Conley.

The many farmers who furnished experimental areas made this study possible. The malathion used in the Selma experiment was furnished by the American Cyanamid Company. The graphs were prepared by George P. Willsey.

LITERATURE CITED

DICKSON, R. C., E. F. LAIRD, JR., and G. R. PESHO
1955. The spotted alfalfa aphid (yellow clover aphid on alfalfa). Hilgardia **24**(5):93–118.

GRAY, K. W., and J. SCHUH
1941. A method and contrivance for sampling pea aphid populations. Jour. Econ. Ent. **34**(3):411–15.

HAGEN, K. S., and RAY F. SMITH
1958. Chemical and biological methods of pest control. Agr. Chem. **13**(7):30–32, 89–92.

SMITH, RAY F., and K. S. HAGEN
1956. Enemies of spotted alfalfa aphid. California Agr. **10**(4):8–10.

STERN, V. M., and R. VAN DEN BOSCH
1959. Field experiments on the effects of insecticides. Hilgardia **29**(2):103–30.

STERN, V. M., R. VAN DEN BOSCH, and D. BORN
1958. New control for alfalfa aphid. California Agr. **12**(1):4–5, 13.

VAN DEN BOSCH, ROBERT
1956. Parasites of alfalfa aphid. California Agr. **10**(10):7, 15.
1957. The spotted alfalfa aphid and its parasites in the Mediterranean region, Middle East, and East Africa. Jour. Econ. Ent. **50**(3):352–356.

VAN DEN BOSCH, R., E. I. SCHLINGER, E. J. DIETRICK, K. S. HAGEN, and J. K. HOLLOWAY
1959*a*. The colonization and establishment of the imported parasites of the spotted alfalfa aphid, *Therioaphis maculata* (Buckton) in California. Jour. Econ. Ent. **52**(1):136–41.

VAN DEN BOSCH, R., E. I. SCHLINGER, E. J. DIETRICK, and I. M. HALL
1959*b*. The role of imported parasites in the biological control of the spotted alfalfa aphid in southern California in 1957. Jour. Econ. Ent. **52**(1):142–54.

4*m*–10,'59(A0816)MR